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Internationale Arbeitsgemeinschaft für Müllforschung (I.A.M.)
Groupe international d'étude pour les recherches sur les ordures ménagères

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MERGER OF IRGRD AND INTAPUC INTO "ISWA"

The "International Research Group for Refuse Disposal" (IRGRD) and the "International Association of Public Cleansing" (INTAPUC) have decided, by mutual consent , to amalgamate and form a new, global association. As from 1 January 1970, therefore, both associations will cease their existence. They will be replaced by the

"INTERNATIONAL SOLID WASTE AND PUBLIC CLEANSING ASSOCIATION" (ISWA)

The German designation will be
"Internationale Vereinigung für Abfallbeseitigung und Städtereinigung."
The abbreviated form, to be used in all languages, will be "ISWA."
The object of this merger is to broaden the scope of the two existing associations, to improve coordination of their efforts and increase work efficiency.
The aims of ISWA are

- Exchange of practical knowledge gained in the fields of deposition, collection, transportation, processing and disposal of domestic and industrial solid wastes and sludges, as well as in street-cleaning, street maintenance in winter, urban motorized traffic, and in other related fields of municipal activity.
- Coordination and promotion of research in all the fields concerned.
- Supplying professional circles with information on new research results, methods of analysis, technical developments, etc., by means of publications in several languages; organizing international conferences and other events, including professional exhibitions.
- Consultations on problems arising within the Association's sphere of activities; it will not be the function of ISWA, however, to act as arbiter.
- Collaboration with the pertinent branches of industry in an endeavor to develop and perfect methods and equipment, in order to meet municipal health requirements.

The statutes of ISWA may be obtained at the following addresses:
German version: Dr. Rudolf Braun, EAWAG, Physikstrass 5, 8044 Zurich
English and French versions: M.C. English, M.A., F.C.I.S.,
28 Portland Place, London W.1.

DEWATERING OF SEWAGE SLUDGE BY CENTRIFUGE

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Forschungsabteilung für Wasser und Abwassertechnik der Cellulosefabrik Attisholz A.G.

1. INTRODUCTION

Wherever liquid sewage sludge cannot be supplied direct to agriculture, the problem of sludge dewatering arises.

The purpose of sludge dewatering is to remove the sludge from the sewage plant in the least expensive way and to transform it into a substance that will permit efficient transportation, dumping, incineration or composting. In other words, the volume, i.e., the water content of the sludge should be reduced to an extent that would make further processing worthwhile economically. However, an important requirement must be met: the return of the 'sewage water' (filtrate, decantate, centrifuge effluent, etc.) to the sewage purification plant, without impairing the safe operation of the latter.

The Cellulosefabrik Attisholz AG has had many years' experience in the centrifugation field, and particularly in the production of nutrient and fodder yeast. It was obvious that this experience might be useful to the company—which is also a builder of sewage purification plants after its own system—in the field of sewage-sludge dewatering; it seemed indicated, therefore, to study the widely propagated idea of sewage sludge dewatering by centrifuge and its applicability.

The following report will afford an insight into the theory and practice of sludge centrifugation and shed light upon the important aspect of operating costs.

2. THEORETICAL CONSIDERATIONS ON CENTRIFUGATION

In principle, the separation process in the centrifuge obeys the gravity laws of sedimentation, but takes place under the influence of the centrifugal force; in other words, the media to be separated (sludge particles and water) must have different densities. The greater the difference, the speedier is the separation process. Hydrodynamic forces also exert an influence, which is considerably more important in the artificially produced gravity field in sedimentation than in a thickener, for instance.

The hydrodynamic resistance of the sludge particles to be sedimented decreases in proportion to their diameter, while their mass decreases with the cube of their diameter. This is the reason why the separation process in the artificial gravity field favors the larger and heavier sludge particles. A certain classification, therefore, takes place in the centrifuges. The largest and heaviest particles settle mainly on the casing of the revolving body. The concentration of solid material decreases steadily towards the center, together with the size and mass of the sludge particles. According to the position of the boundary layer (determined by a scraper disk) the amount of fine-grained material in the centrifugate

can be controlled. Since in practice the sludge cannot be kept in the artificial gravity field for an arbitrary length of time, there is always a classifying effect, and the degree of separation will depend on the position of the boundary.

The ratio of solid matter in the centrifugate to the solid matter in the discharge can be controlled by the position of the boundary. We shall revert to this when describing the practical tests (Figures 2 and 3).

Although much information about the performance of centrifuges can be given by means of various indices, such as centrifugal force, acceleration ratio, surface load, separating grain size, and settling velocity, this will be omitted here, particularly since equally important data on sludge properties, i.e., specific gravity, grain size and viscosity are often only approximately known. The considerations will be limited mainly to values determined in practice.

3. TERMINOLOGY AND DEFINITIONS

The material containing solid matter and thickened by means of the centrifuge is known as **discharge** or **cake**, while the sludge water with the residual solid matter is called **centrifugate** or overflow.

DM = dry matter content (dried at 105°C)
SM = solid matter content (undissolved matter removed by filtration and dried at 105°C)
I = intake of the centrifuge
d = discharge (cake)
C = centrifugate (overflow).

When assessing centrifugation, it is necessary to dishtinguish between degree **of separation** and **separation effect**. The **degree of separation** indicates the actually separated total amount of dry matter, while the **separation effect** expresses in per cent the ratio of the separated solid matter to the solid matter supplied to the centrifuge.

3.1 Degree of Separation

The degree of separation indicates the percentage of dry matter present in the discharge in relation to the dry-matter content of the initial sludge (intake) and can be calculated by the following formula:

$$\text{degree of separation} = 100 - 100\,\frac{DM_C}{DM_I} \cdot \frac{DM_d - DM_I}{DM_d - DM_C}\ \%.$$

3.2 Separation Effect

The separation effect indicates the percentage of solid matter separated by centrifugation, and can be calculated by the following formula:

$$\text{separation effect} = \frac{(DM_I - DM_C) \cdot 100}{SM_I}\ \%$$

where DM_I is the dry matter content of the intake, in %

DM_C the dry matter content of the centrifugate, in %

DM_d the dry matter content of the discharge, in %

SM_I the solid matter content of the intake, in %.

4. DESCRIPTION OF THE EXPERIMENTAL EQUIPMENT

Except for one single test described here, all the tests were performed with decanter centrifuges of various makes and types. Since the principle is the same throughout, the tests performed with the Z_1L and Z_2L decanter centrifuges (high-speed decanters) of the Flottweg Company can be considered representative and shall be discussed here.

4.1 Method

Figure 1 shows a simplified longitudinal section of a decanter centrifuge. The materials to be separated are fed by a pump through the hollow central axis into the high-speed decanter. The solid matter of high specific gravity is deposited by the centrifugal force on the decanter casing, while the lighter liquid forms a ring over it. The liquid naturally is clearest at the ring surface, where it is caught by the scraper disk (which forms the boundary layer) and conveyed outward. The solid matter clinging to the casing is conveyed by a worm conveyor toward the tapering end of the drum and ejected through openings. In this process the solid matter is withdrawn from the level of the liquid ring and hurled out, but only after passing through a dry zone.

The worm conveyor rotates in the same direction as the casing, but at a somewhat higher speed. The difference in speed is caused by epicyclic gearing. The level of the liquid ring can be controlled by means of the scraper disk, which permits the dry zone to be shortened or extended. The drum speed and the speed difference can also be controlled by means of shifting belt pulleys. The throughput is controlled by an auxiliary pump. A single-stage pump was chosen in order to treat the sludge carefully and not to affect its structure.

Flocculating agents can be injected directly into the centrifuge through a pipe inserted in the central axis. This permits a considerably higher degree of separation to be achieved in many cases.

There are various alternative ways of operating a decanter centrifuge

- drum speed control
- speed difference control
- single or double-start worm, or even a disk worm, etc.
- liquid level control by means of the scraper disk
- throughput (duration) control.

Various types of equipment can attain various multiples of the g factor (gravitational acceleration), as follows:

Z_1L		Z_2L		Z_3L	
Speed, r.p.m.	g	Speed, r.p.m.	g	Speed, r.p.m.	g
4,000	1,944	3,500	2,222	3,000	2,100
5,500	3,865	4,500	3,600	4,000	3,733
6,000	4,600	5,000	4,444	–	–
6,500	5,337	–	–	–	–

4.2 Clarification volume of the various types

	Scraper disk	Clarification volume, dm^3
Type Z_1L	130	19,6
Type Z_2L	170	30,7
Type Z_3L	247	74,3

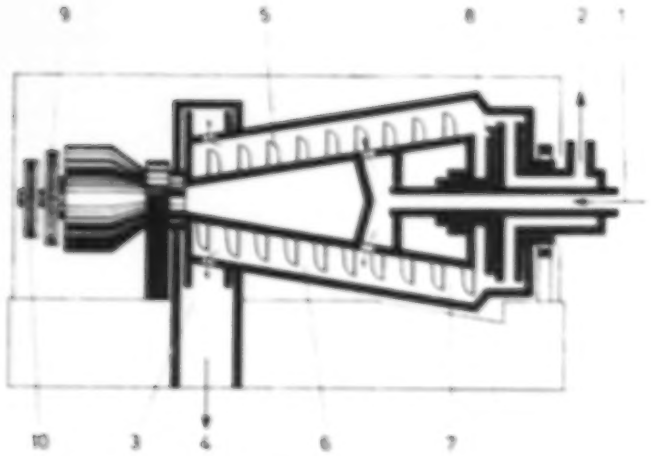

FIGURE 1. Decanter centrifuge (diagrammatic longitudinal section)

1 = sludge intake; 2 = centrifugate (outlet); 3 = ejection shaft; 4 = solid-matter discharge (case); 5 = worm for sludge discharge; 6 = dry zone; 7 = clarification zone; 8 = overflow weir, scraper disk; 9 = drum drive; 10 = worm drive.

5. OWN EXPERIMENTS

Tests 1 through 38 (see Tables 1 – 3) were performed with the high-speed decanter Z_2L at the sewage purification plant Ruttenen (Solothurn). Operating characteristics:

revolutions per minute	4,300
multiple of g (acceleration of gravity)	3,600
difference in speed	50
kind of worm	single start

Aerobic well stabilized sludge from a two-stage, biologically operated sewage treatment plant of the Attisholz system, was used throughout the tests. Tests 1

through 25 were intended to establish the dependence of the degree of separation on the positioning of the scraper disk (Figure 2), and the dependence of the dry-matter content of the discharge on that setting (Figure 3). The results are compiled in Tables 1 and 2 and represented graphically in Figures 2 and 3. The theoretical considerations are thus corroborated in practice.

The influence of the flocculating agent upon the degree of separation and the performance of the decanter were investigated in the subsequent tests 26 through 38. The results can be found in Table 3. The necessary degrees of separation were achieved more readily, together with a better performance of the decanter in general, which naturally entailed a reduction in the operating costs (see below).

Signs of fine-grain enrichment became noticeable in the sewage purification plant during the tests, prompting the author to investigate. The tests were stopped and the plant was allowed a few days of recovery. The tests were subsequently resumed and the plant was fed continuously with the population-equivalent share of the centrifugate. The effluent of the sewage purification plant remained normal as before for several days, then the first and – immediately afterwards – the second stage became more turbid from day to day. The test had to be stopped on the 27th day: the sewage treatment plant was 'choked'.

The following findings were made during that time:

- the ash content of the surplus sludge decreased (see Figure 3)
- at equal performance, the degree of separation dropped every day owing to the recycling of fine-grained material (see Figure 4)
- the dry-matter content of the centrifuge discharge also decreased (see Figure 4).

The findings of Figure 4 confirmed the fact that the ash content in the centrifugate was lower than in the intake and discharge.

The following table of ash contents in three tests corroborates the observations.

Intake		Discharge		Centrifugate	
DM %	Ash %	DM %	Ash %	DM %	Ash %
3,50	46,3	13,2	43,3	0,42	35,6
3,02	46,3	12,4	47,4	0,42	38,0
2,90	42,8	12,4	46,1	0,57	38,6

After the plant had recovered, the tests were repeated and confirmed.

Based on the facts above, it is to be surmised that practically all the fine-grained material fed to the plant leaves it with the effluent, or that it is partly recycled into the centrifuge with the sludge. The 'centrifuge-worthiness' of such material was tested in special experiments with flocculated, thickened and aerated centrifugates. The solid matter – water mixture could hardly be separated anymore. Important conclusions can be reached therefrom, leading to the following question.

What requirements should be met by the degree of separation of a centrifuge?

Answer: To meet the requirements as to the quality of the effluent, the centrifugate should not contain more fine-grained material than can be carried by the discharge pipe.

The necessary degrees of separation in relation to the resulting sludge and the amount of water are plotted in Figure 6. For instance, the following four examples are all based upon a very well operating sewage purification plant for 500 l sewage

per population equivalent/day with a content of 10 mg suspended matter per liter effluent. The effluent may be enriched additionally with 10 mg suspended matter without exceeding the requirements as to suspended-matter content of the effluent. (The Swiss regulations permit a 24-hr average of 20 to 30 mg suspended matter in the effluent.)

Type of sludge	Dry matter in sludge, in g/PE·day	Necessary degree of separation, in %
Raw (mixed) sludge from the activated-sludge plant	150	35 – 36
Well digested sludge	68	32 – 33
Stabilized sludge (Attisholz system sewage treatment plant, biological-chemical)	63	31 – 32
Stabilized sludge (Attisholz system sewage treatment plant, two-stage biological)	61	67 – 68

To meet the requirements for the necessary degree of separation the following measures should be taken.

- The scraper disk of the centrifuge must be positioned so as to ensure a clear centrifugate, of low fine-grain content.
- Effect: by enriching the fine-grained material in the discharge (cake), the dry-matter content of the latter drops rapidly.
- The output of the centrifuge should be restricted to allow the sludge to remain in the centrifuge for a longer period.
- Effect: by enriching the fine-grained material, the dry-matter content of the discharge is reduced in this case, too.
  Both these measures have negative effects on the operating expenses, particularly since a large amount of sludge cakes of high water content must be processed further.
- An admixture of flocculants or sedimentation activators generally has good results, as has already been stated and as will be mentioned again when discussing the operating expenses. The use of such agents is limited, and the sedimentation pattern in the artificial field of gravitation can neither be changed nor neutralized.

Tests 39 through 58 (see Tables 4 – 6) were performed at the Riedholz sewage purification plant which is operated biologically-chemically (third purification stage) after the Attisholz system. A $2\frac{1}{2}$ L. decanter was used.

Equipment characteristics:

Revolutions per minute	3,500
Multiple of g (acceleration of gravity)	3,065
Difference in speed	10
Kind of worm	single start

Earlier tests had made it clear that in the centrifuge well digested sludge behaves in a manner similar to aerobic stabilized sludge. Not much was known about the centrifugation behavior of raw sludge (preliminarily purified sludge, activated sludge). Therefore, a few samples were taken from the Küsnacht ZH activated-sludge plant, and others from the Zug percolation-filter plant. These tests (Nos. 39 – 45) are presented in Table 4. With these types of sludge some-

what higher dry-matter contents seem to be obtained in the discharge, it should be taken into consideration, however, that the resulting amounts of dry matter are considerably higher here than in the digestion process or in aerobic stabilization. Moreover, these were unique samples, and the recycling of fine-grained material had no influence on these tests (cf. Figure 5).

Tests 46 – 58 were again performed exclusively with aerobic stabilized sludge (sewage treatment plant with third purification stage). Much attention was paid here to secondary pollution (BOD_5 and $KMnO_4$). Such pollution is unimportant and may be disregarded.

The operating costs of all tests (Nos. 39 – 58) were calculated on the basis indicated in the section Operating Expenses, including those tests that did not achieve the required degree of separation.

6. TEST No. 59

We had the opportunity of watching two tests at the Birs I (Basel-Land) sewage treatment plant, of taking samples, and making our own evaluations of the tests. The tests were performed with raw sludge in a two-stage combine decanter – disk centrifuge made by a Swedish company. No flocculant was used. The decanter was the first stage, the disk centrifuge the second. The decanter effluent was drained off again in the disk centrifuge.

The overall picture of the test was as follows:

	Dry substance, %		Ash, %	
	Test 59.1	Test 59.2	Test 59.1	Test 59.2
Decanter intake (raw sludge from thickener)	3.97	3.97	43.7	43.7
Decanter intake, solid matter	3.84	3.84	–	–
Decanter discharge (first stage)	32.3	32.9	34.9	34.9
Centrifugate from decanter (first stage) = disk-centrifuge intake (first stage)	2.55	2.51	47.8	35.7
Disk-centrifuge intake, solid matter	2.32	2.38+	–	–
Disk-centrifuge discharge (second stage)	8.88	7.81	33.3	33.3
Centrifugate from disk centrifuge (second stage)	0.81	0.65	23.7	28.6
Discharge of first and second stage mixed in ratio of occurrence	14.1	14.1		

6.1 Test No. 59.1

	Degree of separation, %	Separation effect, %
Decanter (first stage)	41.4	33.6
Disk centrifuge (second stage)	74.0	71.2
Whole system (first and second stages together)	84.9	81.8

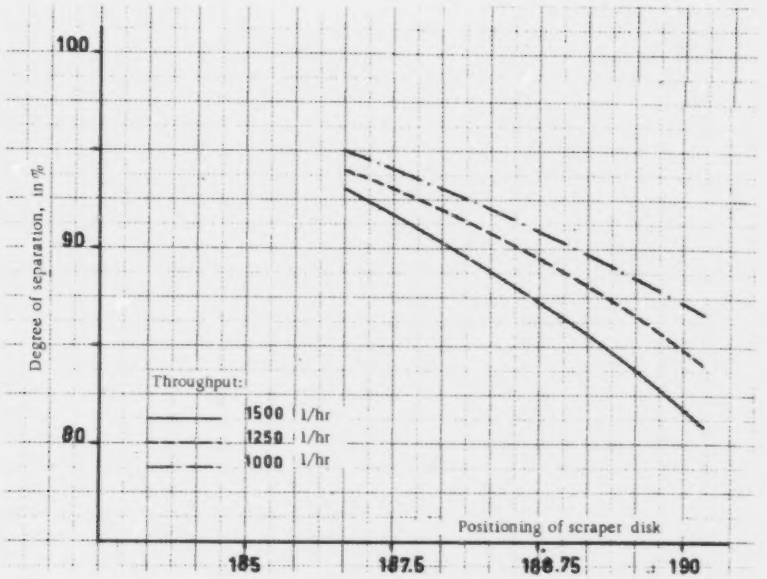

FIGURE 2. Degree of separation vs scraper-disk position

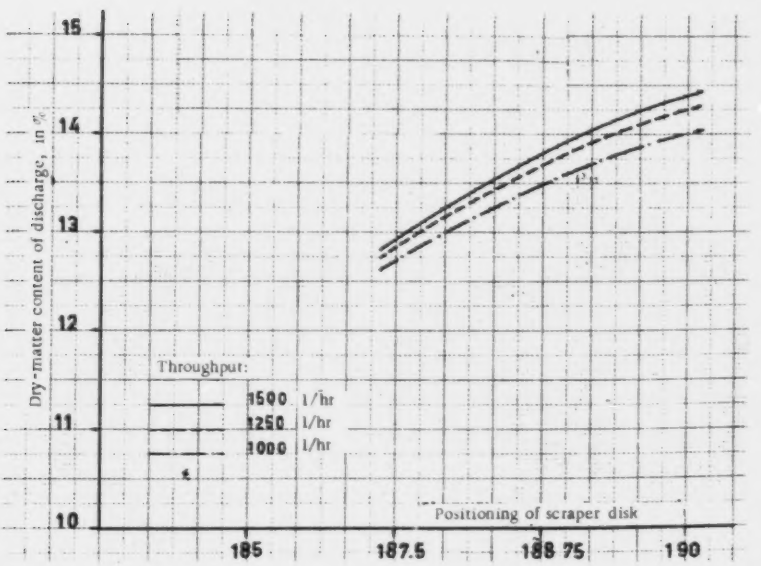

FIGURE 3. Dry-matter content of discharge vs. scraper-disk position

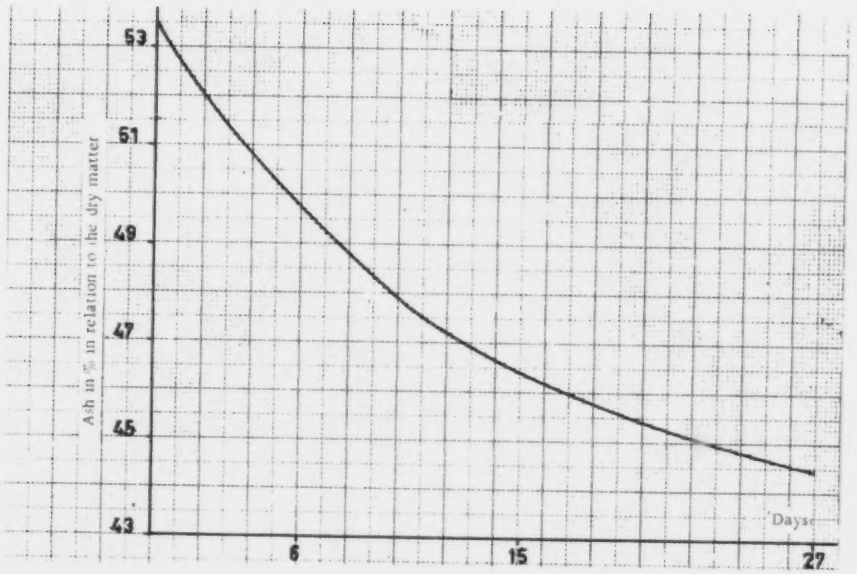

FIGURE 4. Reduction of ash content in the surplus sludge over the 27-day test duration

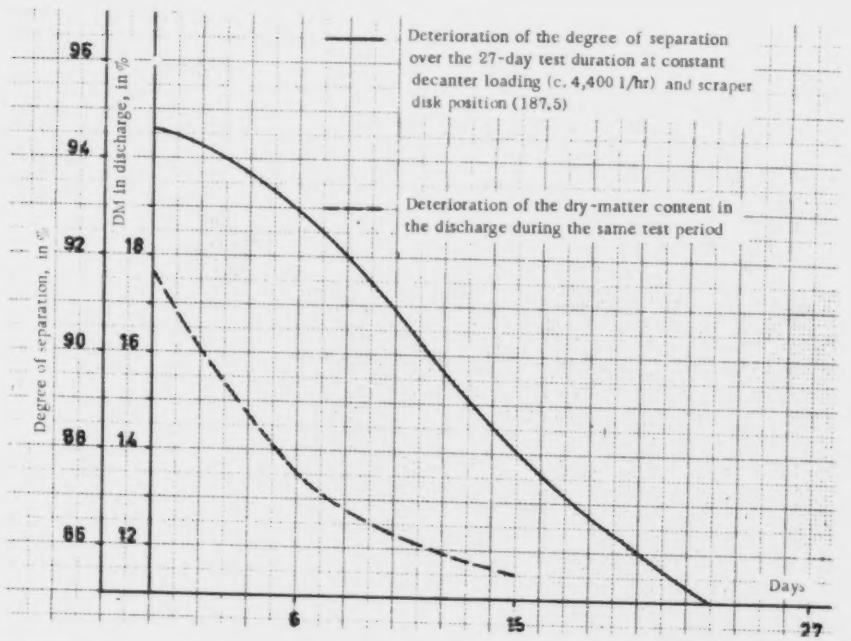

FIGURE 5.

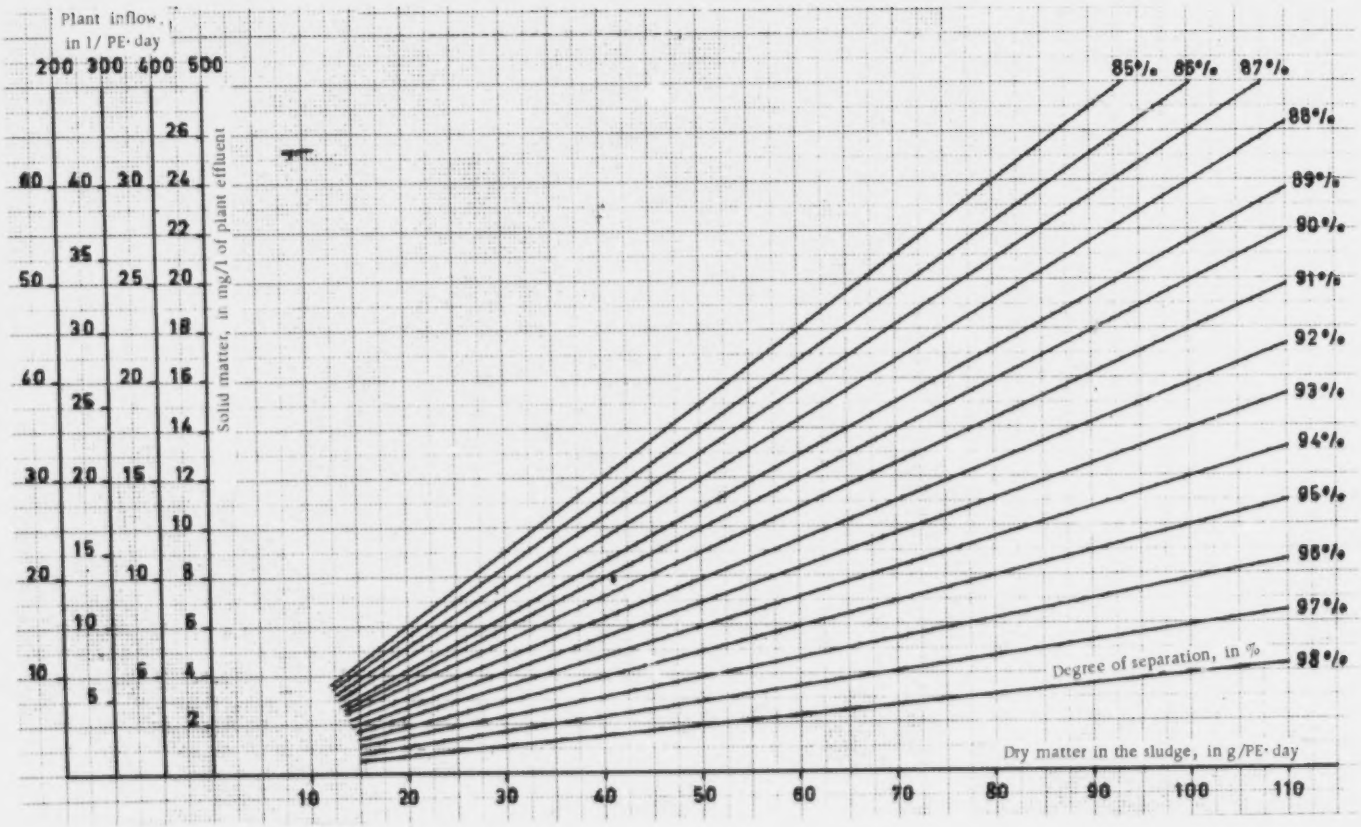

FIGURE 6. Solid-matter increase in the effluent of the sewage-treatment plant, in mg/l, vs. degree of separation of the decanter

TABLE 1.

Test No.	Scraper disk position	Intake				Centrifugate, %	Discharge, %	Degree of separation, %	Separation effect, %
		DM, %	SM %	Throughput l/hr	kg DM/ hr	DM	DM		
1	187.5	2.25	2.18	1,000	22.5	0.14	17.5	94.6	96.8
2	187.5	2.15	2.08	1,000	21.5	0.14	17.0	94.3	96.6
3	192.5	2.21	2.13	1,400	30.9	0.53	17.0	78.5	78.9
4	190	2.22	2.16	1,400	31.1	0.30	16.5	88.1	88.9
5	190	2.15	2.08	1,400	30.1	0.25	16.0	89.8	91.4
6	190	2.10	2.03	1,450	30.5	0.22	17.0	90.7	92.6
7	187.5	2.54	2.46	1,250	31.8	0.23	12.9	92.6	94.0
8	190	2.55	2.46	1,250	31.9	0.52	14.6	82.5	82.6
9	192.5	2.58	2.51	1,250	32.3	0.74	16.0	74.8	73.4
10	195	2.57	2.50	1,250	32.1	0.99	17.7	65.2	63.2
11	185	2.57	2.50	1,000	25.7	0.16	8.9	95.5	96.4
12	187.5	2.56	2.49	1,000	25.6	0.27	13.6	91.8	92.0
13	190	2.52	2.46	1,000	25.2	0.60	14.7	79.4	78.1
14	192.5	2.45	2.38	1,000	24.5	0.51	16.5	81.7	81.6
15	187.5	2.55	2.48	1,000	25.5	0.19	12.6	93.7	95.2
16	188.75	2.55	2.48	1,000	25.5	0.26	13.5	91.6	92.4
17	190	2.55	2.48	1,000	25.5	0.40	14.0	86.8	86.8

TABLE 2.

Test No.	Scraper disk position	Intake				Centrifugate, % DM	Discharge, % DM	Degree of separation, %	Separation effect, %
		DM %	SM %	Throughput l/hr	kg DM/hr				
18	187.5	2.50	2.43	1,250	31.2	0.20	12.7	93.5	94.6
19	188.75	2.55	2.48	1,250	31.8	0.30	13.6	90.2	90.8
20	190	2.40	2.33	1,250	30.0	0.42	14.1	85.1	85.0
21	187.5	2.50	2.43	1,500	37.5	0.25	12.9	91.8	92.6
22	188.75	2.40	2.33	1,500	36.0	0.43	13.7	84.8	84.6
23	190	2.50	2.43	1,500	37.5	0.54	14.3	81.5	80.9
24	187.5	2.55	2.48	1,800	45.9	0.36	13.2	88.3	88.4
25	188.75	2.55	2.48	1,800	45.9	0.57	13.4	81.1	79.8

TABLE 3.

Test No.	Scraper disk position	Intake		Throughput		Flocculant			Centrifugate, % DM	Discharge, % DM	Degree of separation, %	Separation effect, %
		DM %	SM %	l/hr	kg DM/hr	Trade mark	g/m³	g per ton of DM				
26	190	2.12	2.05	2,450	52	–	–	–	0.48	13.27	80.3	80.0
27	190	2.12	2.05	2,450	52	Purifloc A22	20.2	952	0.16	12.50	93.7	95.6
28	190	2.11	2.03	2,450	51.7	–	–	–	0.48	13.12	82.2	80.3
29	190	2.11	2.03	2,450	51.7	Purifloc A22	19.2	908	0.15	12.46	94.0	96.5
30	190	2.11	2.03	2,450	51.7	Purifloc A22	10.8	511	0.34	12.91	86.2	87.2
31	190	2.11	2.03	2,450	51.7	Purifloc A22	16.5	783	0.17	12.38	93.2	95.6
32	190	2.11	2.03	2,450	51.7	Purifloc A22	25.5	1,200	0.16	12.08	93.6	96.0
33	190	2.00	1.93	2,450	49	–	–	–	0.41	12.50	82.2	82.4
34	190	2.10	2.03	2,450	51.4	Nalco 273	17.2	816	0.11	12.21	95.7	98.0
35	190	2.10	2.03	2,450	51.4	Nalco 273	13.6	648	0.12	12.58	95.2	97.6
36	190	2.10	2.03	2,660	55.8	–	–	–	0.42	16.21	82.1	82.8
37	190	2.10	2.03	2,660	55.8	Polymin HS	30.7	1,460	0.23	12.26	90.7	92.2
38	190	2.10	2.03	2,660	55.8	Polymin HS	23.0	1,096	0.17	15.71	92.9	95.2

TABLE 4. (Tests 39– 58 Scraper-disk 140)

Test No	Sludge origin	Sludge type	Intake				Centrifugate				Discharge		Degree of separation, %	Separation effect, %
			DM, %	Ash, %	SM, %	throughput, l/hr	DM, %	Ash, %	BOD_5, mg/l	$KMnO_4$ consumption, mg/l	DM %	Ash %		
30	Küsnacht ZH	Raw sludge	5.85	33.67	5.75	200	0.38	20.77	2,500	3,600	23.81	31.49	95.0	95.0
40	Kusnacht ZH	"	1.58	33.03	1.53	410	0.19	31.80	–	1,300	23.89	40.64	88.1	90.2
41	Kusnacht ZH	"	3.81	31.44	3.71	250	0.47	27.73	–	–	19.65	37.43	89.8	90.0
42	Zug	"	2.93	35.93	2.83	300	0.13	28.20	400	805	24.00	–	95.9	98.8
43	Zug	"	2.93	35.93	2.83	410	0.26	29.74	834	1,285	24.65	41.08	92.3	94.4
44	Zug	"	2.93	35.93	2.83	860	0.18	28.70	700	725	24.59	43.96	94.6	97.1
45	Zug	"	2.93	35.93	2.83	1,000	0.21	28.30	838	980	24.72	44.18	93.5	96.1

	Flocculation				Decanter performance						Operating costs, in SF per m^3 (Z_1L)	Operating costs, in SF per ton DM (Z_2L)
	before decanter		in decanter		Z_1L		Z_2L		Z_3L			
	flocculant	kg per ton DM	flocculant	kg per ton DM	l/hr	kg DM/hr	l/hr	kg DM/hr	l/hr	kg DM/hr		
39	–	–	Polymin P	4.7	200	11.7	800	46.8	1,200	70.2	3.80	64.5
40	–	–	Polymin P	3.2	410	6.3	1,640	25.2	2,460	37.8	1.90	118.0
41	Mafloc	26	Polymin P	4.2	250	9.5	1,000	38.0	1,500	57.0	3.80	95.6
42	–	–	Polymin P	4.5	300	8.8	1,200	35.2	1,800	52.8	2.80	93.3
43	–	–	Polymin P	3.3	410	12.0	1,640	48.0	2,460	72.0	2.00	68.5
44	Mafloc	68	Polymin P	1.6	860	25.2	3,440	101.0	5,160	151.2	1.75	59.0
45	Mafloc	68	Polymin P	1.3	1,060	30.0	4,240	120.0	6,360	180.0	1.50	51.1

TABLE 5.

Test No.	Sludge origin	Sludge type	Intake			Through-put, l/hr	Centrifugate			Discharge		Degree of separation, %	Separation effect, %
			DM, %	Ash, %	SM, %		DM, %	Ash, %	BOD_5, mg/l	$KMnO_4$ consumption, mg/l	DM, %	Ash, %	
46	Riedholz	Stab. sludge	2.42	44.56	2.35	320	0.306	35.25	580	3,070	23.56	48.26	88.4	89.8
47	"	"	3.55	47.05	3.46	300	0.325	23.35	–	–	26.58	48.47	91.9	93.4
48	"	"	2.40	47.79	2.33	320	0.228	31.40	–	–	22.76	48.29	92.3	93.1
49	"	"	3.77	47.42	3.68	270	0.426	33.02	–	–	23.95	49.06	90.2	90.8
50	"	"	2.68	47.32	2.61	300	0.196	29.89	388	1,300	23.84	49.65	93.5	95.0
51	"	"	2.40	44.54	2.32	650	0.194	–	133	486	25.23	49.48	92.6	95.2
52	"	"	2.40	44.54	2.32	450	0.211	–	160	789	24.70	49.99	92.0	94.4

	Flocculation				Decanter performance						Operating costs, in SF per m^3 (Z_2L)	Operating costs, per ton DM (Z_2L)
	before decanter		in decanter		Z_1L		Z_2L		Z_3L			
	flocculant	kg per ton DM	flocculant	kg per ton DM	l/hr	kg DM/hr	l/hr	kg DM/hr	l/hr	kg DM/hr		
46	Mafloc	124	Polymin P	5.2	320	7.7	1,280	30.8	2,080	50.0	3.60	150.2
47	"	85	"	3.8	300	10.6	1,200	42.4	1,950	69.0	3.80	107.3
48	"	125	"	5.3	320	7.7	1,280	30.8	2,080	50.0	3.65	150.9
49	"	106	"	3.9	270	10.2	1,080	40.8	1,755	66.4	4.95	117.6
50	"	111	"	4.8	300	8.1	1,200	32.4	1,950	52.6	3.95	139.7
51	Mafloc / lime	83/125	–	–	650	15.6	2,600	62.4	4,125	101.5	2.10	86.6
52	" "	83/125	–	–	450	10.8	1,800	43.2	2,925	70.2	2.55	105.6

TABLE 6.

Test No.	Sludge origin	Sludge type	Intake				Centrifugate				Discharge		Degree of separation, %	Separation effect, %
			DM, %	Ash, %	SM, %	throughput, l/hr	DM, %	Ash, %	BOD_5, mg/l	$KMnO_4$ consumption, mg/l	DM, %	Ash, %		
53	Riedholz	Stab. sludge	3.72	47.62	3.65	560	0.46	34.17	160	4,930	27.38	52.24	89.1	89.3
54	"	" "	2.35	46.88	2.28	640	0.25	45.77	234	975	25.61	50.00	90.3	92.2
55	"	" "	3.32	43.93	3.24	290	0.27	27.11	710	1,960	23.98	44.79	92.9	94.2
56	"	" "	3.64	42.55	3.58	300	0.18	29.59	310	585	23.95	43.70	95.7	95.6
57	"	" "	4.11	45.99	4.04	330	0.66	30.80	1,220	13,900	24.2	49.60	86.3	85.5
58	"	" "	2.71	43.31	2.64	500	0.16	25.74	180	1,720	23.02	47.68	94.8	96.5

	Flocculation				Decanter performance						Operating costs in SF per m^3 (Z_2L)	Operating costs in SF per ton DM (Z_2L)
	before decanter		in decanter		Z_1L		Z_2L		Z_3L			
	flocculant	kg per ton DM	flocculant	kg per ton DM	l/hr	kg DM/hr	l/hr	kg DM/hr	l/hr	kg DM/hr		
53	Mafloc / lime	54/ 81	–	–	560	20.8	2,240	83.2	3,360	124.8	1.95	60.4
54	Mafloc/ lime	85/ 128	–	–	640	15.0	2,560	60.0	3,840	90.0	2.10	89.4
55	–	–	Meyprofloc 01	0.51	290	9.6	1,160	38.4	1,740	57.6	2.50	75.0
56	–	–	Polymin P	3.65	300	10.9	1,200	43.6	1,800	65.4	2.75	75.4
57	–	–	Mafloc	48.7	330	13.6	1,320	54.4	1,980	81.6	2.70	65.7
58	Mafloc	73.8	Polymin P	1.44	500	13.5	2,000	54.0	3,000	81.0	2.50	80.6

6.2 Test No. 59.2

Decanter (first stage)	40.0	38.0
Disk centrifuge (second stage)	69.8	78.2
Whole system (first and second stages together)	87.5	86.5

Unfortunately, the centrifugate in these tests was not recycled in the sewage treatment plant. Had this been done, it would soon have become obvious that the degrees of separation of 84.6 and 87.5 were insufficient for this sludge, if the required effluent quality of the plant was to be maintained.

7. TECHNOLOGICAL POSSIBILITIES AND OPERATING EXPERIENCE

7.1 Technological Possibilities

The following alternatives can be used for dewatering sewage sludge in centrifuges.

7.1.1 Centrifuge dewatering alone, with or without flocculant.

7.1.2 Multistage centrifuge dewatering with or without flocculant (as described for test No. 59).

7.1.3 Combined centrifuge and filter dewatering (secondary treatment and filtration of centrifugate).

7.1.4 Dewatering by centrifuges combined with drying beds (centrifugate dewatering in drying beds).

For reasons of space, it is unfortunately not possible to go into the details of every procedure.

7.2 Operating experience

Two points will briefly be mentioned here.

7.2.1 Small centrifuges of low clarification volume are prone to clogging, as our own experience has shown.

7.2.2 Continuous observations during several months have shown that the performance of decanter centrifuges steadily deteriorates owing to wear of the worm.

8. OPERATING COSTS

Among other factors, the operating costs are decisive for the selection of a sludge dewatering system. Data concerning these costs vary widely and are too frequently founded on theoretical assumptions. In such cases practical operation often produces very unpleasant surprises. To avoid such surprises, operating costs are calculated on the basis of measured values. In principle, only those instances are taken into account where the degree of separation meets the requirements.

Indication of the operating costs in relation to the cubic meter of dewatered sludge is rather unfortunate. It is better and more correct to refer the data to the dry-matter throughput and then relate them to the population equivalent.

Wages and salaries were deliberately not taken into account in our operating-cost calculations, because the most unlikely manipulations may and do occur in this branch. According to our experience, a sludge dewatering plant should not be automated to an exceedingly large extent, nor should it be operated with night shifts or on a round-the-clock basis, without supervision. It is advisable to operate the plant in the presence of a supervisor. About $^1/_8$ to $^1/_4$ of the operating time should be devoted to servicing.

8.1 Calculation basis for our operating expenses

8.1.1 Electricity

Unit price	SF 0.10 per kWhr
Average power requirement of Z_2L decanter including feed pump	3.5 kW

8.1.2 Chemicals

Magnafloc	SF 0.35 per kg
Polymin	4.– per kg
Meyprofloc 31	12.– per kg
Calcium hydrate	0.12 per kg

All these are delivered-to-consumer prices, for medium-sized shipments.

8.1.3 Servicing and repairs

The centrifuge is subject to wear and tear, depending on the sludge composition. The most sensitive part is the worm. The price mentioned by the supplier for a replacement worm, or the cost of recoating an old worm is SF 6,000 for the Z_2L type. Four thousand hours of trouble-free operation are guaranteed.

$$\text{Cost per hour of operation } \frac{6{,}000}{4{,}000} \quad \text{SF } 1.50$$

The other servicing costs such as lubrication, assembling and dismantling of the worm, etc., may amount to approximately SF 0.20 per hour of operation.

Total servicing and repairs SF 1.70 per hr of operation

The operating cost of Tests Nos. 39 – 58 (see Tables 4 – 6) were calculated accordingly.

8.2 **Examples**

8.2.1 Example 1. Calculation based on Test No. 1.

Decanter performance		1,900 l/hr
DM content of inflow		2.25 %
	corresponding to	22.5 kg DM
Degree of separation		94.6 %
DM content of discharge		17.5 %
Net operating costs:		
electricity consumption, including pumps		
9.5 kWhr/m³, or 22.5 kg DM		SF 42.20 per ton DM
Maintenance and repairs		
SF 1.70 per hour of operation, or		
SF 1.70 per 22.5 kg DM		SF 75.60 per ton DM
Net operating costs, total		SF 117.80 per ton DM
Net operating costs in relation to 1 m³ dewatered sludge		SF 2.65 per m³
Net operating costs in relation to population equivalent (40 g sludge – DM per PE/day)		SF 1.72 per PE/year

8.2.2 Example 2. Calculation based on Test No. 27.

Decanter performance		1,800 l/hr
DM content of inflow		2.55 %
	corresponding to	45.9 kg DM/hr
Degree of separation (unsatisfactory!)		81.1 %
DM content of discharge		13.4 %
Net operating costs:		
Electricity consumption, including pumps		
9.5 kWhr/1.8 m³, or 45.9 kg of DM		SF 20.70 per ton DM
Maintenance and repairs		
SF 1.70 per hour of operation or		
SF 1.70 per 45.9 kg DM		SF 37.– per ton DM
Net operating costs, total		SF 57.70 per ton DM
Net operating costs in relation to 1 m³ sludge		SF 1.47 per m³
Net operating costs in relation to population equivalent (40 g sludge – DM per PE/day)		SF 0.67 per PE/day

Remark: A test yielding an unsatisfactory degree of separation was deliberately chosen in order to show that the operating expenses were significantly lower for such operation. However, the problem of sludge dewatering can not be solved in this way.

8.2.3 Example 3. Calculation based on Test No. 42.

Decanter performance		1,200 l/hr
DM content of inflow		2.93 %
	corresponding to	35.2 kg DM/hr
Degree of separation		95.9 %
DM content of discharge		24.0 %

Net operating costs:	
electricity consumption, including pumps	
9.5 kWhr per 1.2 m^3 or 35.2 kg of DM	SF 27.– per ton DM
Maintenance and repairs	
SF 1.70 per hour of operation or	
SF 1.70 per 35.2 kg DM	SF 48.30 per ton DM
Chemicals:	
Polymin 4.5 kg per ton DM at SF 4.– per kg	SF 18.– per ton DM
Net operating costs, total	SF 93.30 per ton DM
Net operating costs in relation to	
1 m^3 sludge	SF 2.80 per m^3
Net operating expenses in relation to population	
equivalent (108 g sludge – DM per PE/day)	SF 3.68 per PE/year

8.2.4 Example No. 4. Calculation based on test No. 45.

Decanter performance	4,240 l/hr
DM content of inflow	2.93 %
corresponding to	120 kg DM/hr
Degree of separation (barely sufficient)	93.5 %
DM content of discharge	24.72 %
Net operating costs:	
electricity, including pumps 9.5 kWhr per	
4 240 l, or 120 kg DM	SF 7.90 per ton DM
Maintenance and repairs:	
SF 1.70 per hour of operation, or	
SF 1.70 per 120 kg DM	SF 14.20 per ton DM
Chemicals:	
Mafloc 68 kg per ton DM, SF 0.35 per kg	
Polymin 1.3 kg per ton DM at SF 4.– per kg	SF 23.– per ton DM
Net operating costs, total	SF 51.10 per ton DM
Net operating costs in relation to 1 m^3 sludge	SF 1.50 per m^3
Net operating costs in relation to population	
equivalent (108 g sludge – DM per PE/day)	SF 2.02 per PE/year

8.3 Effect of flocculants on operating costs

This shall be illustrated by the following example. Compare Test No. 15 (without flocculant) to Test No. 27 (with flocculant). The tests were performed under practically identical conditions.

		Test No. 15	Test No. 27
Degree of separation	%	93,7	93,7
Throughput	l/hr	1,080	2,450
	kg DM/hr	25.5	52.0
DM content of inflow	%	2.35	2.12
DM content of discharge	%	12.6	12.5
Flocculant Putifloc A 22	kg/ton DM	–	0.35
Operating costs	SF/ton DM	103,80	63.–

Discretion is to be used in interpreting this example, as various factors, e.g., price of flocculant and sludge properties, are involved in flocculation. However, the use of flocculants often helps achieve an increased throughput and thus a reduction in the operating costs; it also helps obtain the required degrees of separation.

9. RESULTS

9.1 Centrifuges are not unconditionally suitable for municipal sewage-sludge dewatering. They are suitable mainly for solving specific sludge problems in industry, or as a preliminary stage.

9.2 Fine-grained matter recycled in the plant with the centrifugate settles unsatisfactorily. It causes disturbances ('choking phenomena') in the sewage treatment plant and affects sludge sedimentation.

Other handicaps, such as BOD_5 and $KMnO_4$, are usually not very serious and may be disregarded, provided the required degrees of separation are attained.

9.3 The degrees of separation are to be chosen in such a way as to avoid any effect on the effluent by secondary loading of the plant by fine-grained matter.

For instance, the following degrees of separation are to be obtained

for 108 g sludge – DM per PE/day (raw sludge)	95 – 96 %
for 68 g sludge – DM per PE/day (digested sludge)	92 – 93%
for 60 g sludge – DM per PE/day (biologically-chemically stabilized sludge)	91 – 92%
per 40 g of sludge – DM per PE/day (biologically stabilized sludge)	87 – 88%

9.4 At the required degrees of separation, dry-matter contents of approximately 16 – 18 % can be obtained in the discharge.

9.5 By keeping the degrees of separation comparatively high, the operating costs rise correspondingly. They fluctuate between SF 60 and 150 per ton of processed dry matter. A reasonable basis of calculation may be SF 100 (without payment on principal) per ton of processed dry matter.

DETERMINATION OF THE DEGREE OF MATURITY OF REFUSE COMPOST

Part 1. Measuring the Oxygen Intake

by H. Allenspach, Town Engineer, Horgen

For the purpose of useful application of refuse compost accurate determination of its maturity degree or state of fermentation is of decisive importance. Again and again complaints are voiced about insufficiently matured compost impeding plant growth and even causing damage, or about compost of indeterminate maturity degree being applied as a cure-all, i.e., as a hot pack as well as a soil-loosening or soil-melioration aid. The methods of examination which are in use at present for determining the state of fermentation of refuse compost are known and require skilled personnel and special laboratory equipment; biological tests, in particular, also require much time.

In collaboration with EAWAG* and the Dano Agency in Switzerland, the sewage purification plant at Horgen carried out a series of examinations in the spring of 1967; in addition to the known methods, such as determination of the C/N ratio and the chaetomium test, a new apparatus, developed in Horgen, was used for measuring oxygen consumption.

Originally it had been planned to submerge a certain amount of compost in water and determine its oxygen intake from the oxygen content of the water. However, since the fermentation processes of compost take place in a gaseous medium, it was suggested to measure the oxygen consumption in just such a medium.

For this purpose, a Plexiglas measuring cylinder was constructed, which allowed visual observation of the main tests. The available air pumps for the circulation of air in the measuring circuit, proved unsatisfactory, because they were not airtight. While looking for a suitable pump, we tried a small fan produced by H. Widner Ag, Zurich, but it did not insure airtightness either. Since the carbon dioxide formed by the decomposition process was compensated, low pressure developed, which in a nontight system drew in fresh air from outside. This resulted in an asymptotic intake curve, from which the actual oxygen consumption could not be established. When at last the "Cyklon" aquarium pump was mounted, conclusive results were obtained, the intake curve proceeding linearly throughout the actual decomposition zone.

After completion of these basic preliminary tests, and through trial and error, the "Compost Measuring Instrument Horgen" was evolved. It is based on the following principles: a weighed quantity of loosely packed compost is introduced into a hermetically closing measuring cylinder of known air volume (Figure 1). By taking into consideration the pore volume of the compost, the total quantity of air in the measuring system can be calculated. This air volume contains a known percentage of oxygen. By correlating this quantity to the prevailing temperature and air pressure, the weight of the initial amount of oxygen can be established. The total amount of air is now circulated in the measuring cylinder, so that the compost confined therein is constantly aerated.

Changes in the oxygen content of the air within the measuring system can be registered by suitable instruments. Tests were made with the Beckman oxygen apparatus produced by Kontron, Zurich, as well as with a borrowed EIL-lightning apparatus produced by Brunner, Zurich. With the Beckman apparatus it was possible to measure the volume percentage or the partial pressure of oxygen, while the EIL apparatus indicated the prevailing partial pressure as a percentage of the overall partial pressure of oxygen. The latter apparatus also required a special probe for measuring the temperature, while the values indicated by the Beckman

* [EAWAG – Federal Institute for the Distribution and Maintenance of Water Resources and Purification of Sewage.]

apparatus over the given temperature range (20°C) were corrected. By correlating this to the local barometric pressure and temperature (Figure 2), the amount of the oxygen was established by weight. Since the carbon dioxide produced by the decomposition process was compensated by soda lime, a region of low pressure in proportion to the consumed oxygen was formed in the system, as already mentioned. In principle, the amount of oxygen consumed could be calculated from the extent of low pressure, the local air pressure and temperature. However, since suitable measuring instruments are now available for direct determination of the oxygen content, the latter seems to be the more practical method.

While mounting the measuring probe in the air circulation system, care had to be taken that it be continuously surrounded by the circulating air. In order to obtain data on the process of oxygen intake, the measuring appliances were connected with a recorder, made available on loan by Messrs. Kontron, for the duration of the first tests.

In order to determine the extent of air displacement caused by the introduction of the compost, 1 kg compost was introduced into a measuring cylinder (see Figure 3) and fully compacted. It was thus possible to determine the compost pore volume to a useful degree of accuracy.

Parallelly to these measurements, the water content of the compost was determined in the drying cabinet in each case. Similarly, the loss on ignition i.e., the organic portion in relation to the amount of solid matter, was determined in the ignition cabinet.

The values obtained for the oxygen consumption, Cons, during a certain time t, for a compost quantity Q resulted in oxygen intake $I = \frac{Cons}{Q \cdot t}$ (mg/kg/t). Since the water content tended to vaccilate around 50%, the value I', in relation to the solid matter content of the compost Q', was also determined, i.e., $I' = \frac{Cons}{Q' \cdot t}$.

In order to maintain a constant temperature, the Compost Measuring Instrument Horgen was placed in a water bath which was maintained at a steady 20°C by a "Unitherm" thermostat. A control test at lower or higher temperatures resulted in considerable variations in the oxygen consumption (Figure 4), while at ± 20°C the values varied relatively little.

It was found that following the introduction of the compost an acclimatization time had to be allowed before a measurable linear oxygen consumption could be observed. In addition, a current of fresh air at 20°C was passed through the entire system for ca. 15 minutes.

The biological processes in fermentation are caused by aerobic decomposition organisms which take in oxygen and give off carbon dioxide. The increasing content of carbon dioxide would cause retardation of microorganism activity. Sodium hydroxide (soda lime) is added to bind the carbon dioxide, so that the oxygen consumption is reflected, indirectly, by low pressure in the measuring system. Depending on the state of fermentation, the activity of the microorganisms can be weaker or stronger, and the oxygen consumption varies accordingly. Continuous tests during the entire duration of the fermentation process have shown that the oxygen intake I is a definite function of the fermentation time. Thus, fresh compost, for instance, which had been activated in a Dano drum, showed an intake I of ca. 300 mg/kg/compost/hr, while towards the end of the fermentation time I decreased to about 30—40 mg, i.e., to ca. 10% of its initial value.

The 1967 tests were carried out as follows:

1. About 1 ton of fresh compost from the Olten Plant was deposited on wooden boards which were placed about 10 cm above the floor in the cellar of the Horgen Purification Plant and built up into windrows of ca. 1.20 m in height. To maintain air humidity at a constant value, a hygrometer with humidifier was installed. A suction fan provided for periodical renewal of the air. At the beginning of the test

series the room temperature was 8°C (beginning of March 1967) and towards the end of the series it increased to 12°C (end of May). The windrows were turned at regular intervals, and simultaneously a certain quantity of water was added uniformly, so that the water content could be maintained as near to 50 % as possible.
2. The first turning took place after one week (on the 5th day), accompanied by addition of 150 l water; the second time the windrows were turned on the 15th day, when again 150 l water were added. On the 28th day the compost was turned for the third time, and 100 l water were added. Further turning was carried out in intervals of 2 weeks (on the 43rd, 57th, 71st and 97th days), without addition of water.
3. The windrow temperature was measured continually and read periodically. To obtain a good average temperature a number of thermometers were used, in a depth of ca. 40 cm.
4. The compost was turned so as to ensure proper aeration of the individual particles.
5. Sampling took place during the turning, so as to obtain a representative average.
6. First, the water content of the samples was determined and their content of organic matter established by means of the loss on ignition. Then the oxygen intake was determined, with the aid of the new measuring instrument.
7. Further samples of the same material were used for laboratory determinations of the C/N ratio and the chaetomium test (EAWAG laboratory).
8. Parallelly with these determinations, germination tests were made with different mixtures, first with standard earth, which served as a blank, then with compost alone, with compost and sand, and with compost and peat. These tests were carried out by Mr. Longin Ziegler from the Rusterholz tree nursery, Oberrieden.
9. On the days on which the windrows were turned, all the participating parties (EAWAG, Dano, Bauamt [Construction Office] Horgen, etc.) met to discuss current results and decide on further procedure.
10. To ensure a supply of compost of a certain degree of maturity for the future, samples were placed in a refrigerator and kept at ca. 2°C.

Determination of the oxygen consumption was carried out as follows:

a) The sample is carefully mixed; 3 kg of it are weighed and introduced loosely into the measuring cylinder. A dish covered with sodium hydroxide is then inserted into the compost. The measuring cylinder, hermetically closed, is placed in a water bath at 20°C and left for ca. 15 min to adjust to the temperature. During that time a current of fresh air at 20°C (room temperature) is passed through the air system of the cylinder.

b) One kg of the carefully mixed sample is packed into a measuring dish and tamped. The tamped compost volume can be read off the scale mounted on the tamper.

c) Duplicate samples of 100 g net each, are taken from the carefully mixed sample, placed in the drying cabinet and dried at 105°C. These serve for determinating the water content, which should be ca. 50 %.

d) Duplicate samples, weighing 100 g net each, are taken from the carefully mixed sample, placed in the muffle oven and calcinated at 600°C. From the loss by ignition, the content of organic matter in relation to the dry-matter quantity is calculated.

e) The air system of the measuring cylinder is connected to the membrane air pump.

f) The oxygen measuring apparatus is adjusted to 21 volume percent of oxygen or its appropriate partial pressure and the measuring probe is mounted on the measuring system.

g) A recorder is connected to the oxygen measuring apparatus and adjusted to zero for the initial value, and set in action with the chronometer. The chronometer speed is adjusted in accordance with the degree of maturity so that clearly legible graphs may be obtained.

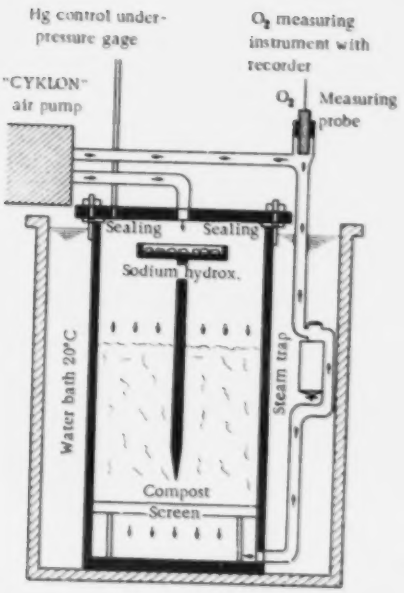

FIGURE 1. Compost measuring instrument Horgen.

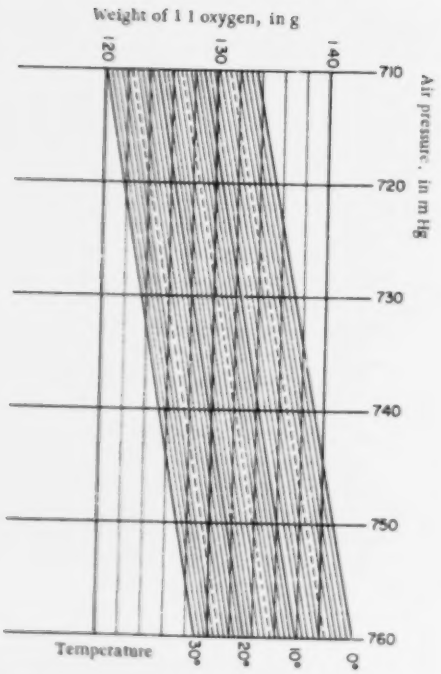

FIGURE 2.

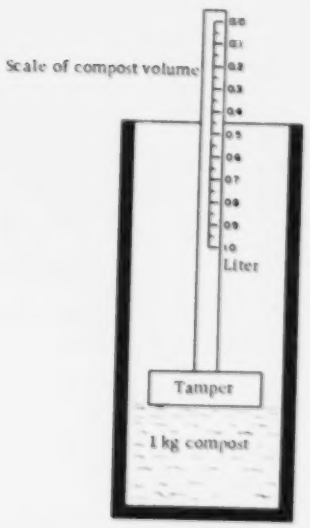

FIGURE 3. Volumetric determination of the compost potex.

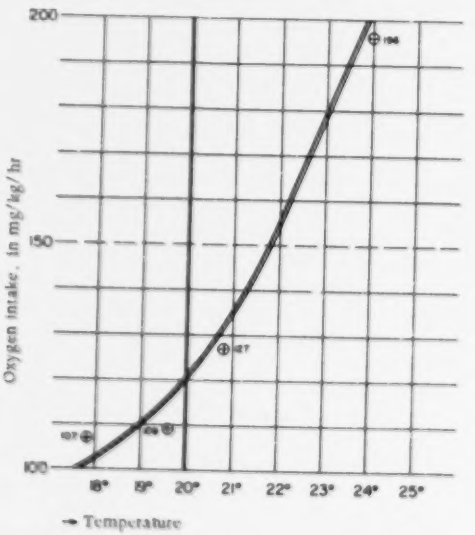

FIGURE 4. Oxygen intake as a function of temperature.

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Oxygen intake tests for compost

Test No.	Date of test	Type of compost	Remarks
U	19.4.1967	Olten	

Compost quantity	3,000 g	1,000 g compost pressed 742 ml
Barom. pressure	730	Organic matter 37.5% of solid matter
Moisture content	50%	Initial compost temperature 30°C
Test temperature	20°C	$I = \frac{7.420 \times 1.28 \times 7.75}{3.0 \times 5.0 \times 100} = 49$ mg
Volume capacity of measuring apparatus	9,650 ml	
Compost displacement	2,230 ml	$I' = \frac{7.420 \times 1.28 \times 7.75}{1.5 \times 5.0 \times 100} = 98$ mg
Air volume	7,420 ml	
Oxygen weight	1.280 g/l	

Time	Reading %	Δ %	O_2 mg	C_2 mg	Δ t_{hr}	Oxygen intake kg/hr
17^{30}	19.0		1,803			
22^{30}	11.25	7.75	1,068	735	5.0	49

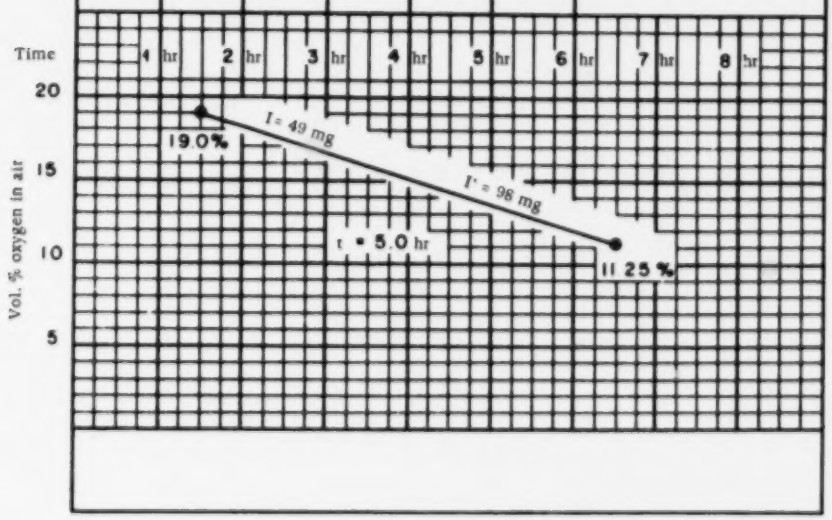

FIGURE 5. Oxygen intake tests for compost.

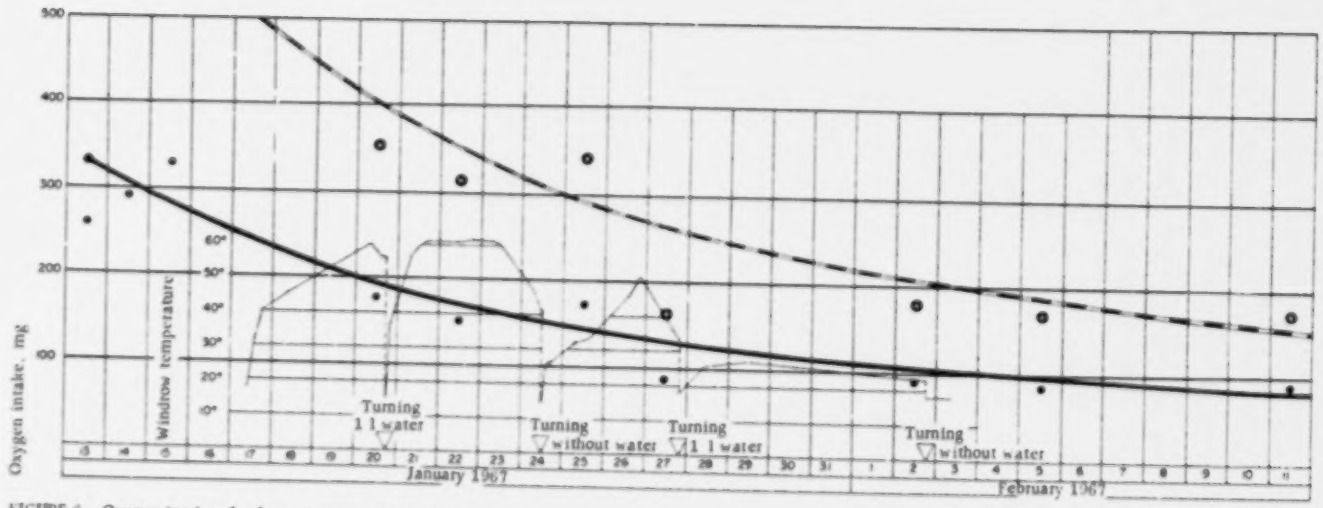

FIGURE 6. Oxygen intake of refuse compost – preliminary test.

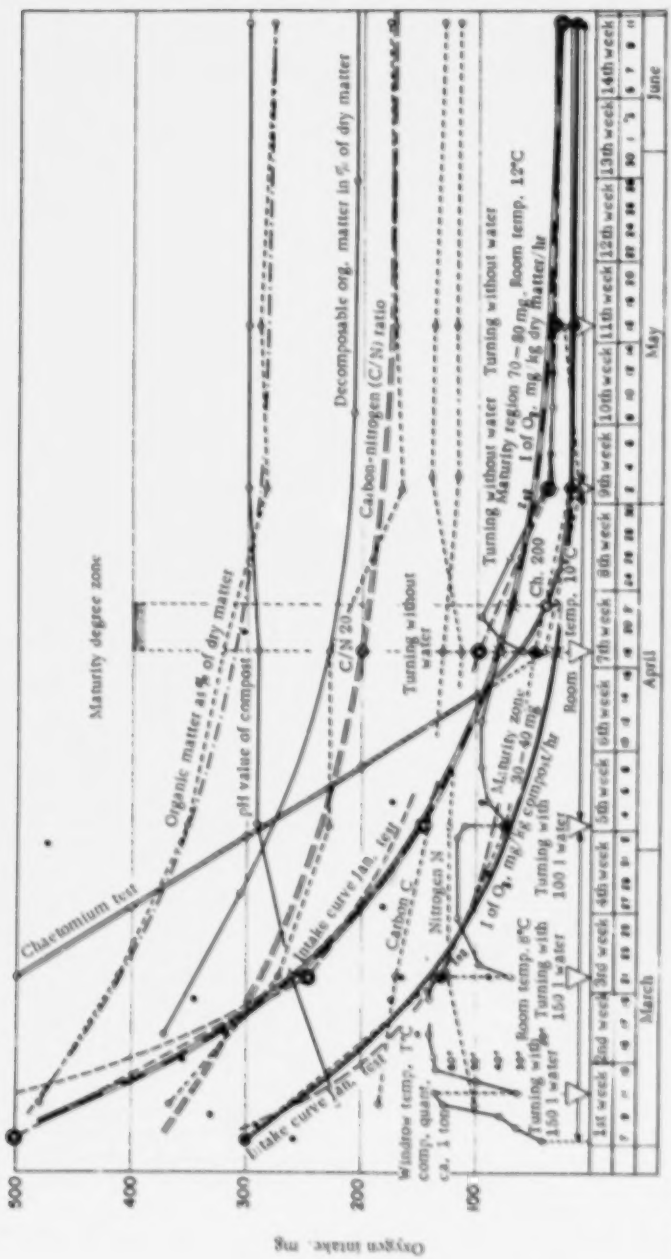

FIGURE 7. Oxygen intake of refuse compost – 1967 test.

h) The thus prepared measuring system is put in operation.
i) Following the acclimatization period of about 30 min in a compost of medium degree of maturity the oxygen consumption is a linear function of time, so that it is not necessary to record the zero value. Within the linear process two values are read off at corresponding time intervals.
k) The total volume of air contained within the measuring system (cylinder, pipes, pump) is known. From this value the volume of the compost introduced (determined tamped volume) is deducted to arrive at the initial volume of air, or oxygen amount. By correlating this value to the temperature and air pressure, the initial quantity of oxygen can be calculated in mg.
l) The oxygen consumption per unit weight and per unit time is defined as follows:

I = oxygen intake in mg/kg compost per hr

I' = oxygen intake in mg/kg

m) As an example, the recorded values are shown in Figure 5.

A. PRELIMINARY TESTS

In January — February 1967, preliminary tests were made with compost from the KEZO Plant of Hinwil, mainly in order to try out the new measuring instruments and installations and to prepare them for the main tests. The results are shown in Figure 6; initial oxygen consumption by fresh compost from the Biostabilizer is seen to be ca. 300 mg/hr per kg compost. After a few weeks and due turning of the compost, this value decreases to 100 mg. Since the compost quantities tested were relatively small (a so-called "basket test"), turning was effected at short intervals, i.e., the compost was turned whenever the temperature showed a downward trend.

B. MAIN TESTS

The preliminary tests were followed by the main tests, performed with ca. 1 ton compost from the Olten Waste-Treatment Plant. The results are shown in Figure 7 and can be summarized as follows:

1. Oxygen intake of fresh, activated Dano compost is ca. 300 mg/kg compost/hr or ca. 600 mg/kg solid matter/hr. With increasing maturity, this value decrases to ca. 10% of the initial value. (For comparison — the oxygen intake of peat dust was found to be ca. 16 mg/kg/hr, while the intake of so-called standard earth was 13 mg/kg/hr).
2. The curve for the C/N ratio also shows a decreasing value with time. At a C/N ratio of ca. 20 the oxygen curve shows a I-value of ca. 30 mg/kg compost/hr or a I'-value of ca. 80 mg/kg solid matter/hr.
3. The curve for the chaetomium test falls sharply in the first fermentation phase, has an inflection at 200—300, and thereafter proceeds more or less asymptotically with time towards zero. Analogous to the chaetomium test count of 200 is the I-value of ca. 25 mg/kg compost/hr (or I' = ca. 70 mg/kg solid matter/hr on the oxygen curve).
4. On the basis of these provisional results, it may be assumed that the oxygen intake of mature compost with a chaetomium test count of ca. 200 and a C/N ratio of ca. 20 lies in the region of I = 30-40 mg/kg compost/hr or I' = 70-80 mg/solid matter/hr. Further tests should be carried out to corroborate these values.

5. In these tests the quantity ratio of organic substance to solid matter in the maturity zone was shown to be 30 – 32 %, decreasing somewhat with further fermentation.
6. The pH value increases with advancing decomposition from an initial ca. 7.0 to ca. 8.0, remaining stable thereafter.

The aforementioned fermentation tests were carried out with refuse compost from the Olten Plant and the results, therefore, are not representative. However, tests with refuse compost from the Hinwil Plant gave analogous results, as already mentioned. A further test series should clarify the conditions for a mixture of refuse compost and sewage sludge and determine analogous values; presumably, the I – values will be somewhat higher.

In the course of the tests, the firm Elmes Richterswil was kind enough to make available a recording apparatus for a certain period; later a Philips recording apparatus was obtained on loan.

After the Horgen Regional Composting Plant (11 associated municipalities of the district) was put in operation, a further test series, on the same lines as the 1967 tests, was again initiated in collaboration with EAWAG. Refuse compost from the Horgen plant, mixed with sewage sludge, was used.

In the course of the tests, the measuring apparatus was improved. In determinations in gaseous media, the oxygen probe must remain free of condensation water. For this purpose, a steam trap was fitted into the circuit.

Connecting and disconnecting the various hoses was also somewhat troublesome; this was remedied by fitting them with Oetiker hose couplings which proved very serviceable.

The measuring cylinder for determining the pore volume was also improved (Figure 8), so that this operation now proceeds smoothly and quickly.

The measuring equipment is explained in Figure 9.

The new tests began in mid-April 1968 and lasted until the end of July 1968. As already mentioned, refuse compost from the Kniebreche Plant, mixed with an equivalent quantity of sewage sludge, was used. The values indicated in Figures 10 and 11 were determined by EAWAG; in this connection, the reader is referred to the tables by Dr. Obrist. Figure 10 shows the water content curves during the 1967 and 1968 tests; it should be noted that during the 1968 tests room temperature and room humidity could not be kept constant (rapidly decreasing moisture content, sprinkling of the compost after 6 weeks).

Also shown in Figure 10 are the comparative 1967 and 1968 values for total organic matter, decomposable matter and total dry matter. The somewhat higher content of organic matter is due probably to the addition of sewage sludge.

Figure 11 indicates the nitrogen and carbon contents as well as the C/N ratio for 1967 (without sludge) and 1968 (with sludge). It is seen that the nitrogen content of the 1968 material was ca. 75 % higher than that of the 1967 material; in this connection it should be remembered that the materials were derived from different sources (1967: Olten; 1968: Horgen).

The carbon content, too, was ca. 15 % higher in 1968 than in 1967, probably for the same reason. Consequently the values of the C/N ratio also varied; in 1967, for instance, the ratio was 22.8 after 4 weeks; in 1968 – 17.3; after 8 weeks, the ratio for 1967 was 16.7, for 1968 – 12.8.

The chaetomium counts in Figure 11 show differences between 1967 and 1968, the values for the first decomposition stage in 1967 (without sludge) being considerably higher. At the end of the fermentation process, the differences are still considerable, and it remains for the scientist to clarify whether these differences stem from the specific properties of the materials or whether they are due to the addition of sewage sludge.

The oxygen intake measurements carried out in the course of the 1968 tests are shown in Figure 12; after about 10 weeks, they gave the following values:

Oxygen intake per compost quantity – ca. 30 mg/kg/hr
per quantity of solid matter – ca. 80 mg/kg/hr
per quantity of organic matter – ca. 150 mg/kg/hr

After this period the oxygen intake curve flattens and approaches values similar to those for garden mold (ca. 10–20 mg/kg/hr).

Comparison of the 1968 decomposition curves with those of earlier tests (Figure 13) shows that the oxygen intake values per quantity of solid matter for Olten (January 1967), Horgen 1967 with compost from Olten, and Horgen 1968 with Horgen compost, roughly agree within the maturity zone i.e., at the end of 6–8 weeks the results approach an average end value. Determinations with compost from Hinwil, however, for reasons unknown, deviated from these values.

The windrow temperatures as well as the above-mentioned values are shown in Figure 14. Here it is seen that the maturity degree, as reflected by the oxygen intake, still lies at the inflection on the chaetomium test curve, i.e., where activity slows down; at the same time this value is considerably lower than in former determinations, whereas the C/N ratio in this zone is ca. 13 and not ca. 19 as before.

Figure 14 also shows the values of the redox potential as determined by EAWAG; with advancing fermentation these move from the negative into the positive zone. From the wealth of results obtained from various determinations it was attempted to establish the optimum moisture content for fermentation. According to Figure 15, this value would appear to be ca. 52–53%. A higher moisture content (56–58%) or a moisture content below 50% obviously causes a reduction in activity. Oxygen determinations should be carried out at 52% to 54%, which should be the moisture content of the compost. The latter will thus be prevented from becoming "sticky" and will have the consistency required for soil melioration (crumbly and porous).

When determining the pore volume, numerical values were also entered (Figure 16). With decreasing moisture content the volume per unit weight increases. Whether this relationship is linear or not is outside the scope of this article (swelling due to water, etc.).

For comparison with the above-mentioned numerical values, a further example of the intake values in bulk windrows of a standard plant is cited. In mid-March measurements were made of the oxygen intake of compost windrows in various stages of fermentation. These measurements gave values analogous to those found in the experimental windrows, but fermentation times were considerably longer than in the smaller windrows with optimal conditions (Figure 17). The specific weight of the compost at different degrees of maturity was also determined preliminarily in a very simple manner.

Parallelly with these measurements, plant tests were carried out by EAWAG; the values obtained should be corroborated by further tests, which should also include different plant species.

In connection with these compost tests, grateful acknowledgement is due to all parties concerned: EAWAG, Purification Plant Horgen, Refuse Treatment Plant Horgen as well as the firms which placed their apparatus at the disposal of this research for long periods and often free of charge. The results of these tests should facilitate supervision and control of the fermentation process by the waste experts at the composting plants. Special care was taken to ensure that the measurements were carried out by trained personnel and that the results were available within a short time. Control and supervision of the fermentation process will ensure adequate supplies of ripe compost and will prevent damage or growth retardation.

FIGURE 8. Tamper for determination of pore volume.

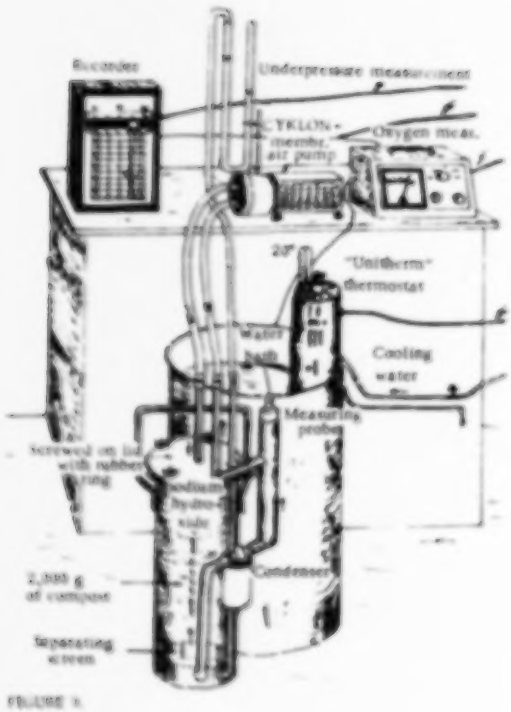

FIGURE 9.

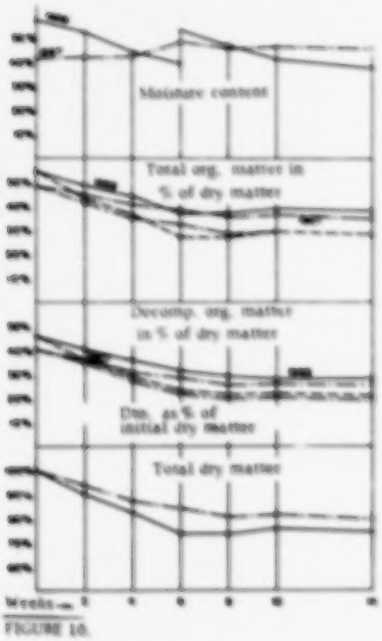
Moisture content
Total org. matter in % of dry matter
Decomp. org. matter in % of dry matter
Decomp. as % of initial dry matter
Total dry matter
Weeks

FIGURE 10.

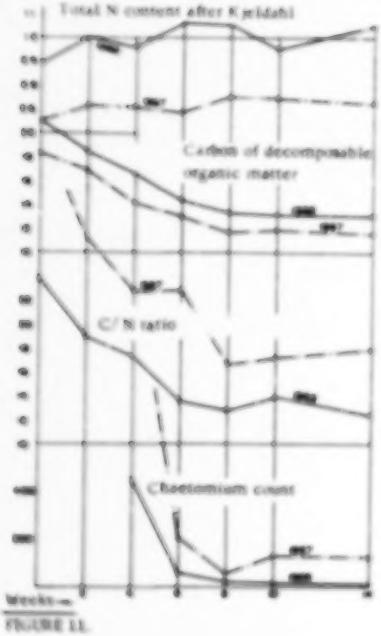

FIGURE 11.

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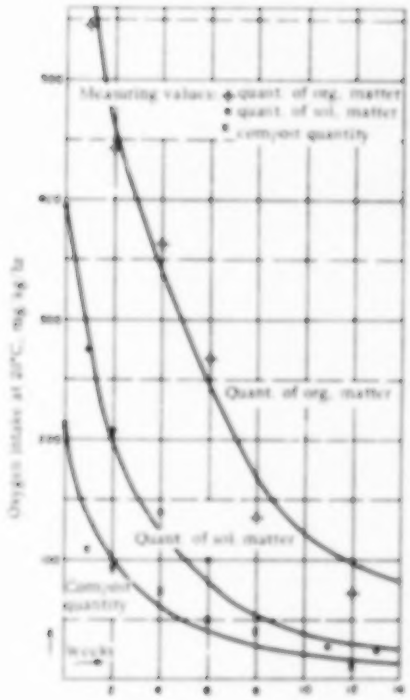

FIGURE 12

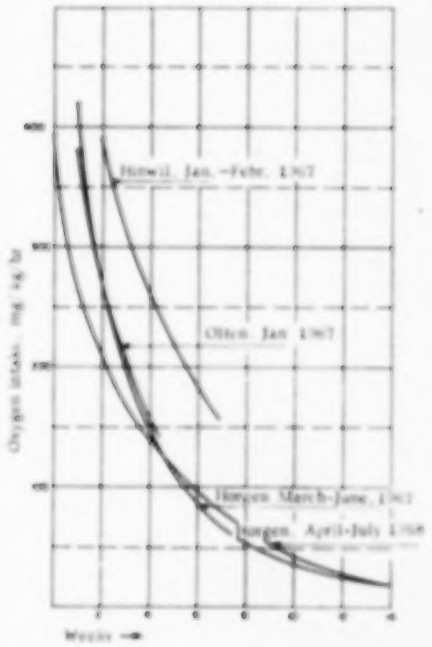

FIGURE 13. Oxygen intake per kg solid matter.

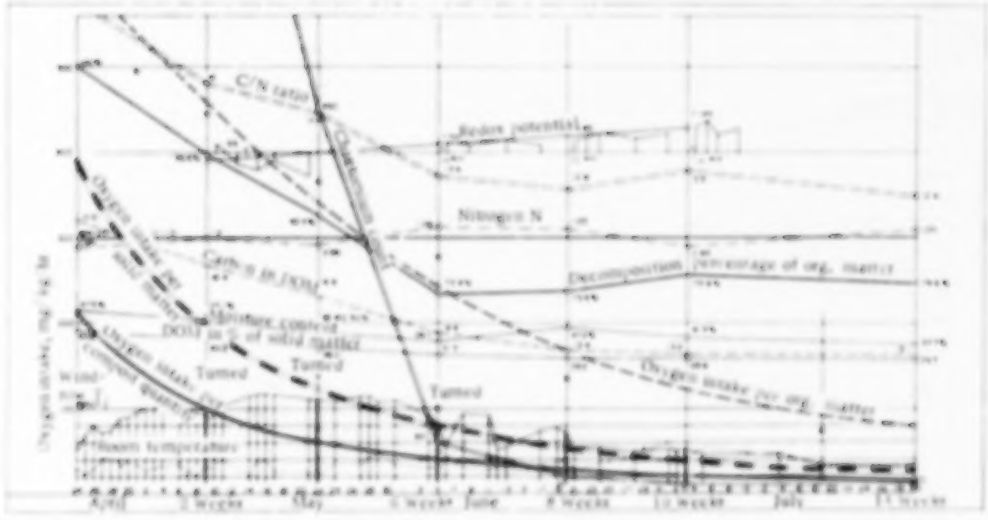

FIGURE 14. Unit test

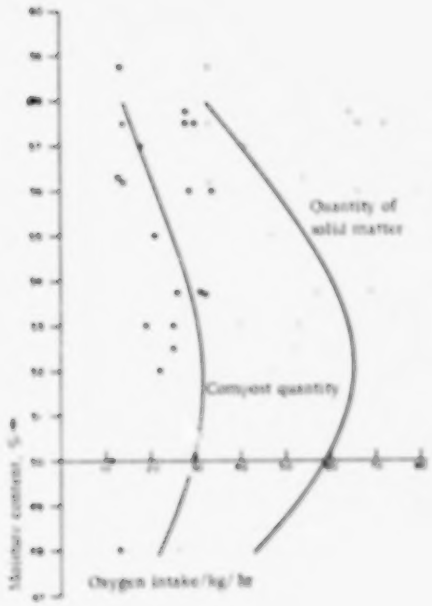

FIGURE 16. Compost determination.

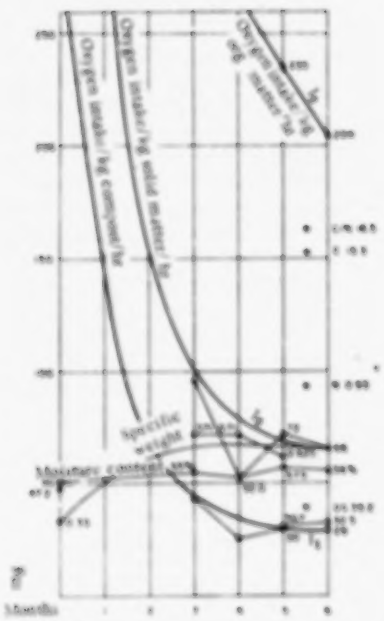

FIGURE 17.

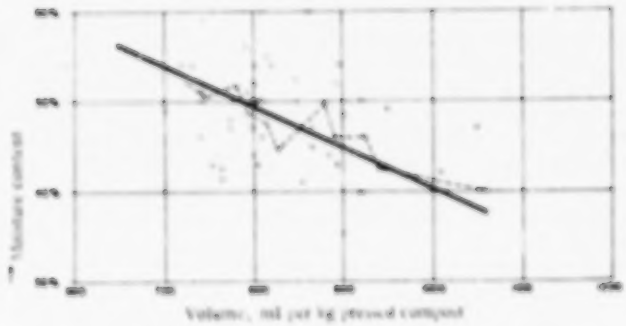

Figure 18. Measurement of compost moisture content and volume per weight of pressed material.

Details of the laboratory compost tests and the plant tests are presented in the EAWAG information section of this Bulletin.

Part 2. Characteristics of the Fermentation Process

by W. Obrist, EAWAG, Zurich

Ever since the establishment of large-scale plants for the composting of domestic and bulky refuse, attempts have been made to establish the characteristics of the processes taking place during fermentation, by means of measured data. These data should primarily serve to distinguish the compost maturation processes, i.e., the mineralization and humification of the decaying refuse. Ultimately, these measurements should allow better evaluation of the compost quality on the basis of the "fermentation or maturity degree," and make possible optimum utilization of compost in agriculture. During the last few years, several methods have been developed for this purpose and have been published; they are based on the following principles: self-heating (**Niese** 1963); oxygen intake, or carbon dioxide formation (**Stichting Compost** 1965; **Spohn** and **Kneer** 1968; **Chrometzka** 1968 a); C/N ratio and decomposition of organic matter (**Obrist** 1967); redox potential (**Tepe, Leidenfrost** and **Darlowsky** 1966; **Möller** 1968); germ counts (**Ahrens, Farkasdi** and **Ibrahim** 1965); growth of fungi (**Chrometzka** 1968 b; Obrist 1965, 1967). It was therefore decided to investigate whether these methods were applicable in practice for composting domestic refuse with or without sewage sludge, and to what extent the different methods were comparable. As a matter of further interest, the chemical, physical and microbiological values obtained were to be compared with the results of plant tests.

We are much obliged to Messrs. Allenspach, Hadorn and Weidmann of the Horgen Refuse Utilization Plant, as well as to Mrs. A. Laube and Messrs. A. von Hirschheydt and G. Rollé of EAWAG for their active support and their collaboration in these investigations.

Conditions of Testing

The 1967 test. In a pump room of the Horgen (Zurich) Purification Plant ca. 1 ton fresh compost from the Olten Refuse Utilization Plant (Dano-Bühler-OFAG system), which had been prefermented in a Biostabilizer for 2 to 3 days, was piled in a coniform windrow of approximately 1.2 m in height. The room temperature rose from 8°C at the beginning of the test in March to 12°C by the end of May. The windrow temperature was measured daily at a depth of ca. 40 cm. The relative humidity of the air was maintained at above 70% by means of a humidifier and a hygrostat. Up to the age of 10 weeks, the windrow was thoroughly turned with a spade every 2 weeks and its moisture content maintained by addition of water at ca. 45% of its fresh weight. Representative samples were taken each time the windrow was turned and also after 14 weeks.

The 1968 test. A similar composting test was carried out in 1968 in the newly established Refuse Utilization Plant at Horgen (combined incineration and composting plant, Dano-Bühler-OFAG system). This time, it was aimed at obtaining a mixture of equivalent refuse and sludge quantities. Based on the assumption that the dry-matter yield per inhabitant/day is 500 g refuse and 70 g digested

sludge, we mixed a total of ca. 1,000 kg fresh compost (prefermented in the Bio-stabilizer 2 – 3 days) with 400 kg sewage sludge that had been dewatered by centrifuge to a 75% moisture content and was supplied by the Pfannenstiel (Zurich) Regional Refuse Utilization Plant. Portions of 20 kg refuse and 8 kg thickened sludge each were mixed in a concrete mixer. Initially the sludge failed to mix evenly, forming small compost-coated sausages ("croquettes"); these disintegrated, however, after only 2 weeks. The coniform windrow of ca. 1.1 m height was set up in a building shed and left to ferment from the end of April to the end of July, in a manner similar to the 1967 test; room temperature and humidity, however, showed greater fluctuation (the temperature fluctuated between 10 – 25°C). The windrow was turned at the end of 2, 4, 6, 8, 10 and 14 weeks and mixed samples were withdrawn each time.

Test Methods

The samples were taken to the EAWAG laboratory where they were promptly dried cautiously (at 50°C) and pulverized in a ball mill. The following values were then determined:

MC = moisture content in % of fresh substance
OM = organic matter in % of dry matter
% IDM = % of initial dry matter
DOM = decomposable organic matter in % of dry matter
ROM = resistent organic matter in % of dry matter
TM = total dry matter
C in DOM = carbon in decomposable organic matter
C/N = carbon/nitrogen ratio
N = total nitrogen after Kjeldahl
Ch = chaetomium count
pH = pH value

The analyses were carried out according to the IAM Collection of Methods (1969). Determination of the oxygen intake was described by H. Allenspach (1969).

Determination of the redox potential: for the 1968 test, a suspension was prepared from 2 – 10-week-old samples of fresh compost and with distilled water in the proportion 1:3; after 30 – 300 min the redox potential of this suspension was measured within 1 – 2 min by means of the redox electrode EA 216, manufactured by Metrohm (Herisau, Switzerland), and the pH meter E 396 by the same company.

Determination of self-heating: based on the tests carried out by Niese (1963), the self-heating temperatures of fresh-compost samples of different ages and maturation stages were measured in a Dewar vessel of 700 ml capacity, by means of NiCrNi – thermoelements and recorded by a Philips point recorder. The material used for the measurement is loosened, mixed, and moistened to a moisture content of ca. 50%. The Dewar vessel and recorder are kept at constant room temperature of 20°C. The decisive value is that of the maximum temperature during a 3 – 5-day period.

Plant seedling test: for method, see IAM Collection of Methods (1969).

Results

The average values (i.e., of double determinations made in 4 parallel samples) are represented in Tables 1 and 2. Table 3 shows the redox potential values of the 1968 test.

TABLE 1. 1967 test

Date	MC	Age, weeks	OM		DOM		ROM	TM	N	C	C/N	Ch	pH
			%	% IDM	%	% IDM		% IDM		in DOM			
6.3.67	41.5	0	48.0	48.0	40.0	40.0	8.0	100	0.5	18.3	36.6	>2,000	7.2
21.3.67	41.8	2	44.4	41.5	36.8	34.4	7.6	93.5	0.62	16.9	27.2	>2,000	7.6
3.4.67	42.5	4	40.4	35.2	30.7	26.8	9.7	87.2	0.62	14 1	22.8	1,430	7.9
18.4.67	48.3	6	38.2	32 2	28.3	23.8	9.9	84.2	0.57	13.0	22.8	210	7.9
2.5.67	45.8	8	35.3	28.2	25.5	20.5	9.8	80.3	0.70	11.7	16.7	60	8.0
16.5.67	46.5	10	36,2	29.2	26.0	21.1	10.2	81.2	0.69	11 9	17.2	130	8.0
13.6.67	45.8	14	34.8	27.8	25.2	20.1	9.6	79.8	0.65	11.6	17.9	125	8.0

TABLE 2. 1968 test

Date	MC	Age, weeks	OM		DOM		ROM	TM	N	C	C/N	Ch
			%	% IDM	%	% IDM		% IDM		in DOM		
24.4.68	57.5	0	53.8	53.8	45.8	45.8	8.0	100	0.89	21.0	23.8	
9.5.68	52.1	2	48.7	43.7	40.2	36.2	8.5	89.9	1.0	18.4	19.0	
22.5.68	44.1	4	44.0	36.3	36.0	29.7	8.0	82.5	0.96	16.6	17.3	340/550
5.6.68	39.7	6	37.1	27.2	31.5	23.2	5.6	73.4	1.06	14.4	13.6	50/70
20.6.68	47.2	8	37.3	27.4	29.3	21.6	8.0	73.6	1.05	13.4	12.8	2/40
3.7.68	41.5	10	39.0	29.4	28.8	21.8	10.2	75.6	0.95	13.2	13.9	2/25
30.7.68	37.7	14	37.9	28.2	28.5	21.2	9.4	74.4	1.05	13.1	12.4	8/11

TABLE 3. Redox potential measurements

Age, weeks	Time of measurement after preparation of suspension, min	Redox potential, mV		
		mixed sample	core zone	fungus zone
2	30	+ 50	0	+ 20
	90	− 70	− 50	− 40
	150	−100	−160	− 70
	200	− 50	−140	− 100
	300	−140	−190	− 140
4	60		−170	+ 30
	90		−180	+ 30
	150		−270	+ 30
6	30	+ 60		
	60	+ 50		
	90	+ 40		
	200	+ 70		
	300	+ 40		
8	30	+ 80		
	60	+ 90		
	90	+110		
	150	+100		
	200	+ 80		
	300	+110		
10	30	+150		
	60	+190		
	90	+100		
	150	+140		

Visible fungal growth (white or gray mold mycelia) was observed to penetrate the entire windrow from the outer layer in the direction of the core within 6 weeks. In the 1968 test the windrow showed a massive overgrowth of Coprinus ("intry cap") fruiting bodies after 4 weeks. In this test the high initial moisture content caused the formation of a brown-black wet core zone that gave off a slightly sweet to sulfide-type odor; it disappeared only after 6 weeks. The final product of both tests after 14 weeks' fermentation was a brown, humus-type, crumbly compost.

In the self-heating test the following values were attained:

Age of sample, weeks	Maximum temperature, °C
4	40 – 45
6	30
8 and above	20

The seedling test, according to A. von Hirschheydt (1968), showed "a picture of almost synchronous increase of the age and height coefficients. Six-week-old compost generally gave the poorest results. From this it should be concluded that this age phase harbors certain growth-impeding factors which are not yet inherent in 4-year-old compost. Due allowance will have to be made, however, for these transition-stage factors; accordingly, on using compost of this age

(with otherwise equal treatment), growth setbacks in the course of the vegetation period are to be expected. Certain symptoms (e.g., appearance of the roots) indicate that the disappearance of these factors is not complete even in a 10-week-old compost."

Discussion

Analysis of the results reveals an initially rapid decomposition process gradually slowing down in windrows both without and with the addition of sewage sludge. In the latter, the high nitrogen content presumably has a decomposition-promoting effect. The oxygen intake curve follows a similar course. The determination of the redox potential indicates an unequivocal tendency to pass from negative to positive values, but with considerable scatter.

The limited results obtained so far by the self-heating tests, without parallel determinations, agree with earlier results obtained by Niese (1963). The equipment used here is simpler and does not permit finer differentiation of the fermentation degrees; it may be used, however, for practical determination of the maturity degree. A further test should be carried out under the actual conditions of windrow-composting, preferably in combination with plant tests.

The seedling tests show that material which from the decomposition aspect could be termed "mature," may yet be subject to further transformation. There may be a kind of "stabilization process."

Conclusions

1. The test procedure selected (low windrow, frequent turning) brought about the expected rapid degradation of domestic refuse and refuse-sludge mixture, within a few weeks, to ca. half their original total and decomposable organic dry matter, or to 75 – 80% of the total dry matter (mineral and organic).
2. The termination of the intensive fermentation phases (degradation phase) is characterized by the following values

C/N ratio	< 19.0 (on addition of a large quantity of sewage sludge – 15.0)
Chaetomium count	< 300
Redox potential	transition from negative to positive values
Self-heating	< 30°C
Oxygen intake	as per Allenspach (1969)

3. Determination of the C/N quotient, the chaetomium count and the oxygen intake requires suitable laboratory equipment and skilled personnel as well as a certain time expenditure. Redox potential and self-heating can be measured with simple equipment and relatively quickly.

The measurement of the redox potential is still not sufficiently accurate, owing to the wide scatter of the values; erroneous determinations might be made in the case of very humid material from large windrows. The measuring procedure for self-heating may require several days, but has the advantage of being simple. Like the oxygen intake, it measures the activity of the decomposition organisms and is a good indicator of the sum-total of all the microbiological decomposition processes. These methods may therefore be applied in composting plants, but major experience is lacking as yet.

4. The seedling test shows that during the long "stabilization process" following the intensive fermentation phases, processes may still take place that could influence plant growth. In connection with the application of compost in agriculture, it is advisable therefore to carry out plant tests according to the specific problems that may arise.

Bibliography

Ahrens, E., G. Farkasdi, and I. Ibrahim. Einige Kriterien zur Charakterisierung der Müllrotte (Some Criteria for the Characterization of Refuse Digestion). – IAM Information Bulletin No. 24, pp. 17 – 24. 1965.

Allenspach, H. IAM Information Bulletin No. 35. 1969.

Chrometzka, P. Bestimmung des Sauerstoffverbrauchs heranreifender Komposte (Determination of the Oxygen Requirement of Maturing Compost). – IAM Information Bulletin No. 33, pp. 7 – 11. 1968a.

Chrometzka, P Der Einfluss von verschiedenen Reifestadien des Kompostes auf das Wachstum von Bodenpilzen (The Effect of Different Maturity Stages of Compost on the Growth of Soil Fungi). –Org. Landbau, Issue 11, p. 36, 1968b.

Hirschheydt, A. von. – Unveröffentlichtes Manuskript vom 20.11.68. (Unpubl. Manuscript dated 20 November 1968).

IAM Collection of Methods. Polycopy, Zürich, IAM. 1969.

Möller, F. Redoxpotential und hygienischer Gütezustand von Siedlungsabfallkomposten (Oxidation-Reduction Potential and the Hygienic State of Compost from Urban Refuse). –IAM Information Bulletin No. 32, pp. 22 – 28. 1968.

Niese, G. Versuche zur Bestimmung des Rottegrades von Mülkomposten mit Hilfe der Selbsterhitzungsfähigkeit (Tests for Determining the Maturity Degree of Refuse Composts by their Self-Heating Ability). –IAM Information Bulletin No. 17, pp. 3 – 14. 1963.

Obrist, W. Enzym-Aktivität und Stoffabbau im rottenden Müll (Enzymatic Activity and Degradation of Matter in Refuse Digestion). – IAM Information Bulletin, No. 24, pp. 120 – 129. 1965.

Obrist, W. Versuche über die Mietenkompostierung von zerkleinertem Hausmüll (Experiments with Windrow Composting of Comminuted Domestic Refuse). – IAM Information Bulletin No. 29, pp. 279 – 284. 1967.

Spohn, E. and F. Kneer. Über die Atmung von Kompost (On the Breathing of Compost). – Org. Landbau, Vol. 11, pp. 68 – 71. 1968.

Stichting Compost Jahresbericht 1965, Polykopie (Ann. Report, 1965, Polycopy). 1965.

Tepe, W., E. Leidenfrost, and A. Darlowsky. Einsatz von Schnellmethoden an Müll-Klärschlammkomposten zur Überprüfung des Rotteverlaufes (Application of Rapid Methods for Examining the Fermentation Process in Refuse-Sewage Sludge Composts). –IAM Information Bulletin No. 28, pp. 256 – 262. 1966.

DISCUSSION

Combustion Quality in Refuse Incineration

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The importance of the combustion quality in refuse incineration must be viewed from two altogether different aspects: its importance for determining the manner of

operation of a given furnace installation, and its importance in the selection of a suitable type of furnace.

Every furnace can be operated with varying loads. Up to a certain throughput capacity, depending on the properties of the furnace as well as of the refuse, good combustion can be attained; but beyond that, greater efficiency can be achieved only at the expense of the combustion quality.

The advantages of high throughput capacity must be weighed against the disadvantages of a lower combustion quality. According to R. Braun (1), the disadvantages are:

Inferior Heat Utilization

In most cases this is not of major importance, since heat production diminishes only very little even with inferior combustion.

Aftereffects in Clinker Tips

These are not very serious either, since even in the case of refuse tips, as is well known (2), groundwater pollution is caused by the mineral rather than the organic refuse components.

Larger Quantity of Clinker

With satisfactory combustion, the clinker contains 5 – 8 % of dry substance lost on ignition and about 20 – 25 % moisture. Expressed in terms of the carbon content of decomposable organic matter (3,4), this constitutes 2.5 – 3.5 %.

Those concerned with refuse incineration know that unburnt residue consists mainly of paper and cardboard. Bundles of newspapers and cardboard packaging are also materials that burn very slowly. The carbon content in these materials lost on ignition is ca. 45 %, and when the fire is extinguished the amount of water bound is about 150 % of their weight.

On this basis the quantity of clinker (including fly ash, scrap metal and sludge) resulting from the incineration of a given type of refuse can be calculated as follows:

Loss on ignition		25% (Refuse 1)	35% (Refuse 2)
Good combustion	(2.5% C-DOM)	34%	47% clinker
Poor combustion	(6.0 % C-DOM)	41%	57 %
Very poor combustion	(10.0% C-DOM)	49%	67 %

The increase in the weight of clinker as a result of poor combustion is not negligible. The determination of C in DOM of the dry matter content of the clinker, or rather the chemical process of oxygen consumption stoichiometrically converted to carbon assuming that only carbon is oxidizable, seemingly gives relatively low values. This fact can easily lead to the erroneous assumption that an increase or decrease of C in DOM of only a few percent is insignificant.

In fact, however, incineration with low-quality combustion achieves little more than does controlled tipping, because in dumps organic matter is also partly decomposed.

Incineration, therefore, serves a useful purpose only if a certain combustion quality can be attained.

For the selection of a furnace, therefore, an efficiency guarantee without guaranteed combustion quality may be misleading and prevent fair comparison.

Bibliography

1) Braun, R. Wie weit soll der Müll ausgebrannt werden? (To What Final Degree Should Refuse be Incinerated?)– IAM Information Bulletin No. 34. 1968.
2) Pollution of Water by Tipped Refuse.– HM's Stationery Office, London. 1961.
3) Oršanić, B. Methode zur Bestimmung des C in AOS in der Müllschlacke (Method for the Determination of Carbon of Decomposable Organic Matter in Refuse Clinker).– IAM Information Bulletin No. 26. 1966.
4) Rollé, G. Über die Bestimmung der Ausbrandqualität von Asche und Schlacke aus Müllverbrennungsanlagen (Determination of the Quality of Incineration of Ash and Clinker from Waste-Incineration Plants). IAM Information Bulletin No. 26. 1966.

LITERATURE RECEIVED BY THE SECRETARIAT

Adams, R.C. Famine, Population and Waste.–(Compost Science, Autumn, Vol. 9, No. 3, p. 23–26. 1968.

Arndt, K.H. and A. Gottschalk. Erfahrungen mit Müllschlacken und Schlackenaufbereitungsanlagen (Experiences with Refuse Clinker and Clinker Processing Plants).–Aufbereitungs-Technik, Issue 10, pp. 510–516. 1968.

Bolek, M. Möglichkeiten zur Verbesserung der Ergebnisse bei der Vakuumfiltration (Means for Obtaining Better Results in Vacuum Filtration).– Aufbereitungs-Technik, Issue 10, pp. 494–499. 1968.

Bopp, R. Abfallbeseitigung, insbesondere Kehrichtverbrennung (Waste Disposal, Particularly Refuse Incineration).–Schweiz. Blätter für Heizung und Lüftung, Issue 2, pp. 55–64, Zurich. 1968.

Bosse, J. Ein Versuch zur Bekämpfung der Bodenerosion in Hanglagen des Weinbaues durch Müllkompost (An Attempt at Controlling Soil Erosion in Sloping Vineyards by Means of Refuse Compost).–Weinberg und Keller, Vol. 15, pp. 385–397. 1968.

Busse, O. Problematik der Frischschlammbeseitigung und ihre Lösung (Problems of Raw Sludge Disposal and their Solution).–Aufbereitungs-Technik, Issue 10, pp. 500–505. 1968.

Dahl, H. Mechanisierte Mietenkompostierung in der Praxis, 1. Teil (Mechanized Windrow Composting in Practice, Part 1).–Kommunale Dienstleistungen, Issue 5, 4th year of publ., pp. 16–17, Dresden. 1968.

Dahl, H. Mechanisierte Mietenkompostierung in der Praxis, 2 Teil (Mechanized Windrow Composting in Practice, Part 2).–Kommunale Dienstleistungen, Issue 1, 5th year of publ., pp. 16–17, Dresden. 1969.

Defèche, J. La nouvelle usine d'incinération d'Ivry.– Techniques et Sciences Municipales, 64th year of publ., No. 1, pp. 23–28, Paris. 1969.

Farkasdi, G., A. Golwer, K.H. Knoll, G. Matthess, and W. Schneider. Mikrobiologische und hygienische Untersuchungen von Grudwasserverunreinigungen im Unterstrom von Abfallplätzen (Microbiological and Sanitary Investigations of Groundwater Pollution in the Underflow of Tipping Sites).– Städtehygiene, Issue 2, 7 pp., 1969.

Grüneklee, H.G. Zur Praxis der Bepflanzung von Abfall-Lagerplätzen. Erfahrungen aus dem Ruhrgebiet (On the Practice of Planting on Refuse Tipping Sites – Experiences in the Ruhr District).– Der Forst-und Holzwirt, 23rd year of publ., Issue 23, 4 pp., Verlag M. and H. Schaper, Hannover. 1968.

Hiebsch, R. and R. Seidenberg. Neue Kompostfräse für industrielle Kompostierung (A New Rotary Cutter for Industrial Composting). — Kommunale Dienstleistungen, Issue 4, 4th year of publ., p. 18, Dresden. 1968.

Hintsches, E. Müllplätze — Gefahr für das Grundwasser (Tipping Sites — A Danger to Groundwater). — Zeitung f. kommunale Wirtschaft, No. 1, München. 1969.

Hirsch, M. and R. Rasch. Beitrag zur Bildung von Eisenchlorid durch Reaktion zwischen Chlorwasserstoff in Rauchgasen und Eisenoxyd in Flugaschen und auf Wärmeaustauscheroberflächen (Formation of Ferric Chloride by Reaction between Hydrogen Chloride in Flue Gases and Ferric Oxide in Fly Ash and on Heat-Exchanger Surfaces). — Aufbereitungs-Technik, 9th year of publ., Issue 12, 11 pp., Verlag für Aufbereitung, 6200 Wiesbaden. 1968.

Hirschheydt, v., A. Industrieschlämme in der Müllkompostierung? (Industrial Sludges in Refuse Composting?). — Kommunalwirtschaft, Issue 1, 6 pp. 1969.

Johnson and Anderson, Inc., and Ducker Research Co. Economic Feasibility Study for Michigan Refuse and Sludge Composting Plant. — Compost Science, Autumn, Vol. 9, No. 3, pp. 7 — 17. 1968.

Klaus, H., H. Kleindienst, and H. D. Peiper. Die Einführung der Siedlungsabfallverwertung (Introduction of Municipal Refuse Utilization). — Kommunale Dienstleistungen, Issue 5, 4th year of publ., pp. 18 — 19, Dresden. 1968.

Kott, F. Grundsätze für Preisbildung für Müllkompost (Basic Principles in Price Calculation for Refuse Compost). — Kommunale Dienstleistungen, Issue 1, 5th year of publ., pp. 18 — 19, Dresden. 1969.

Kumpf, W. Müll-und Abfallbeseitigung — eine kommunale Aufgabe? (Refuse and Waste Disposal — a Municipal Task?). — Wasser Abwasser, Issue 2, pp. 35 — 41, München. 1969.

Kutzschbauch, K. Grundlagen und Grundsätze für die Planung von Kapazitäten zur Siedlungsabfallverwertung (Basic Principles in Planning Municipal-Refuse Utilization Plants). — Zeitschr. f. d. gesamte Hygiene u. ihre Grenzgebiete, Issue 1, pp. 9 — 13, 102 Berlin. 1969.

Mahlke, H. Leistung und Entlohnung in der Müllabfuhr (Efficiency and Wages in Refuse Collection). — Der Städtetag, Issue 3, pp. 152 — 155. 1969.

Mercer, W. A. and W. W. Rose. Windrow Composting of Fruit Waste Solids. — Compost Science, Autumn, Vol. 9, No. 3, pp. 19 — 21. 1968.

Möhler, B. Die landwirtschaftliche Verwertung des Abwasserschlammes, Dokumentation und Kurzreferate der Veröffentlichungen von 1946 — 1967 (Utilization of Sewage Sludge in Agriculture. Documentation and Abstracts of Publications of the Years 1946 — 1967). — Published by: Kuratorium fur Kulturbauwesen, 333 pp., Verlag Wasser und Boden, 2 Hamburg. 1968.

Mohr, R. Spezialkrane für Müllbeseitigungsanlagen (Specialty Cranes for Refuse Disposal Plants). — Müll/Abfall/Abwasser, Issue 9, pp. 30 — 34, Verlag A. Schweiger, 516 Düren. 1968.

Müller, H. J. Städtereinigung in 20 Jahren (Town Cleansing in 20 Years). — Der Städtetag, Issue 12, pp. 651 — 654. 1968.

Netzel, G. Die mechanische Entwässerung von Abwasserschlämmen (Mechanical Dewatering of Sewage Sludge). — Aufbereitungs-Technik, Issue 10, pp. 506 — 509. 1968.

Onasch, H. and Th. Rossi. Anfall von Hausmüll und Kosten seiner Beseitigung (Domestic Refuse Yield and its Disposal Cost). — Der Städtetag, Issue 1, pp. 42 — 43. 1969.

Orth, H. Konferenz des Instituts of Public Cleansing in Brighton (Brighton Conference of the Institute of Public Cleansing in Brighton). — Der Städtetag, Issue 12. 1968.

Pauschmann, H. Der Einsatz von Gas-Chromatophoren in der Abfallwirtschaft (The Use of Gas Chromatophores in the Refuse Economy). – Festschrift Wassergütewirtschaft, Abfallbeseitigung, Probleme, Lösungen; from the Series "Stuttgarter Berichte zur Siedlungswasserwirtschaft," pp. 283 – 296. 1968.

Presse-u. Informationsamt der Bundesregierung Bonn. Brennpunkt Müll-problem (Focus on the Refuse Problem). – Publ.: Fränkischer Tag GmbH and Co., Bamberg. 1968.

Schild, K., A. W. Schmid, and F. Fritz. Abwassersanierung und Kehrichtbeseitigung in der Region Grenchen, 1. Teil (Sewage Purification and Waste Disposal in the Grenchen Region, Part 1). – Gesundheitstechnik, 3rd year of publ., No. 2, pp. 35 – 42, VIW-Verlag Zürich. 1969.

Schluricke, M. Strassenreinigung – ein ernstes Problem unserer Städte (Street Cleaning – A Serious Problem in our Towns). – Städtereingung, 5th year of publ. Issue 4, pp. 73 – 77. Wien. 1968.

Schrader, Th. Möglichkeiten zur Humusversorgung der Weinberge (Possibilities of Humus Supply to Vineyards). – Rebe und Wein, Issue 1 and 2, 4 pp., Jahrbuch-Verlag, 7102 Weinsberg. 1968.

Schulte, F. Jahrestagung des Verbandes privater Städtereinigungsbetriebe in Kassel (Annual Convention in Kassel of the Association of Private Town Cleansing Enterprises). – Der Städtetag, Issue 2, pp. 94 – 98. 1969.

Seng, H. Planungsgrundlagen der Abfallbeseitigung (Planning Principles for Waste Disposal). – Der Städtetag, Issue 12, pp. 654 – 657. 1968.

Seng, H. Die Beseitigung fester Abfallstoffe – die neue gesundheitstechnische Aufgabe (Disposal of Solid Waste – A New Task in Health Requirements). – Korrespondenz Abwasser, No. 10, pp. 204 – 206, Bonn. 1968.

Sparr, A. E. Sludge Handling. – Journal Water Pollution Control Federation, Special Features, Part 1, August 1968, pp. 1434 – 1442, Washington D. C. 20016. 1968.

Tenney, M. W. and T. G. Cole. The Use of Fly Ash in Conditioning Biological Sludges for Vacuum Filtration. – Journal Water Pollution Control Federation, Research Supplement, Part 2, August 1968, pp. R281 – R302, Washington D. C. 20016.

Toth, S. J. Chemical Composition of Seven Garbage Composts Produced in the United States. – Compost Science, Autumn, Vol. 9, No. 3, pp. 27 – 28. 1968.

Wagenknecht, P. Stand der Beseitigung von Altölen, ölhaltigen Schlämmen und ähnlichen Abfällen (Present State of Removal of Used Oils, Oil-Containing Sludges and Similar Waste). – Der Städtetag, Issue 3, pp. 149 – 151. 1969.

Witte, O. Abfallzerkleinerung (Refuse Comminution). – Der Städtetag, Issue 3, pp. 151 – 152. 1969.

Wuhrmann, K. Vom Ausbrand des Mülls (On the Combustion of Refuse). – Kommunalwirtschaft, Issue 1, 4 pp. Düsseldorf. 1969.

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